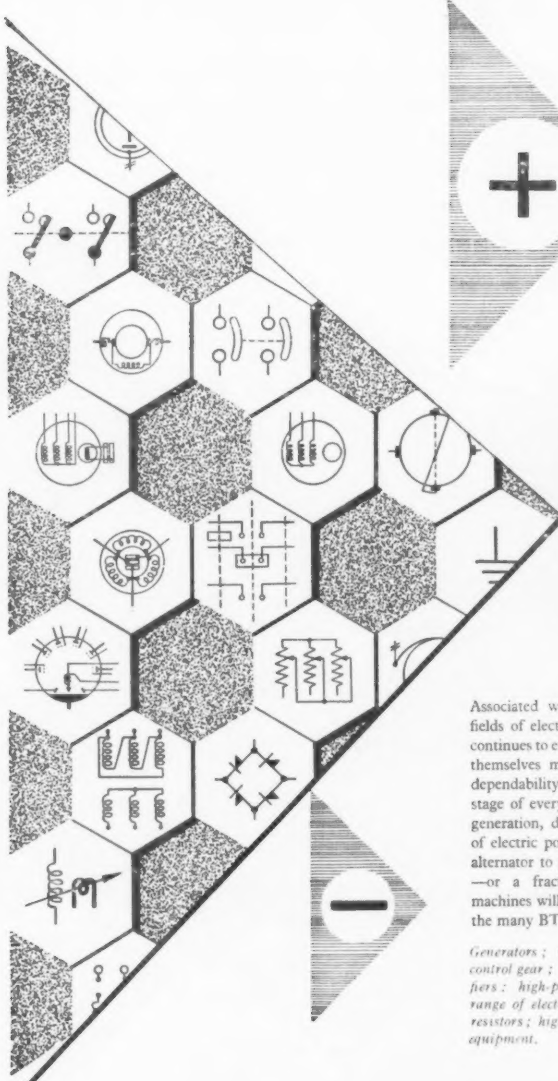


Journal of the Royal Society of Arts

NO. 5023 JUNE 1958 VOL. CVI

AWARD OF THE ALBERT MEDAL TO H.M. THE QUEEN

A. Armstrong Jones *Camera Press Ltd.*

The Queen has been graciously pleased to accept the award of the Albert Medal for 1958, made by the Council and approved by The Duke of Edinburgh as President of the Society. The award is made 'to mark Her Majesty's personal service to arts, manufactures and commerce, at home and abroad'.

Since her accession, the Queen has been unsparing in her efforts to encourage development in all those spheres of activity in the Commonwealth with which this Society is especially concerned. Her Majesty has undertaken public engagements on a scale greatly exceeding that of any previous reign. Industry has derived much benefit and pleasure from the Queen's appreciation of its many-sided progress, whether she is touring the industrial areas of the North and Midlands of this country, or signalizing, by her presence, the magnitude of concerted structural and engineering achievements, such as the Daer Valley Water Scheme, Calder Hall, and the Trans-Canada Highway.

Commerce, similarly, has greatly prospered through the Queen's overseas visits. The manner in which Her Majesty has fulfilled exacting programmes in the Commonwealth and other overseas countries has excited the highest admiration—a feeling compounded not only of respect for her great office, but of delight in the sincerity, grace and charm of her personality.

FINAL MEETING OF THE SESSION

WEDNESDAY, 28TH MAY, at 2.30 p.m. '*The Brussels Universal and International Exhibition*, 1958', by Charles Hadfield, C.M.G., Controller (Overseas), Central Office of Information, and United Kingdom Deputy Commissioner-General for the Brussels Exhibition. Sir Alfred Bossom, Bt., LL.D., F.R.I.B.A., J.P., M.P., Chairman of Council of the Society, in the Chair. (The paper will be illustrated.)

ANNUAL GENERAL MEETING

The Council hereby gives notice that, in accordance with the Bye-Laws, the Two Hundred and Fourth Annual General Meeting, for the purpose of receiving the Council's Report and the Financial Statements for 1957, and for the election of officers, will be held on Wednesday, 25th June, 1958, at 3 p.m., at the Society's House.

(By Order of the Council)

KENNETH WILLIAM LUCKHURST,
Secretary.

PROGRAMME FOR THE 205TH SESSION

The Council will shortly be considering the programme of meetings for the forthcoming Session. Fellows are invited to forward suggestions for lectures and papers to the Secretary by 16th June.

CONFERENCE ON APPRENTICESHIP

As announced in the last issue of the *Journal*, a one-day Conference on Apprenticeship will be held at the Society's House on Wednesday, 9th July, 1958. Fellows who wish to attend should apply to the Deputy Secretary before 20th June.

MEETING OF COUNCIL

A meeting of Council was held on Monday, 12th May, 1958. Present: Sir Alfred Bossom (in the Chair); Mrs. Mary Adams; Dr. W. Greenhouse Allt; The Honble. G. C. H. Chubb; Sir Edward Crowe; Mr. Robin Darwin; Mr. P. A. Le Neve Foster; Mr. John Gloag; Sir William Halcrow; Mr. A. C. Hartley; Dr. R. W. Holland; Mr. Edgar E. Lawley; Mr. F. A. Mercer; Mr. O. P. Milne; Sir William Ogg; Sir Harold Saunders; Sir Selwyn Selwyn-Clarke; Sir Stephen Tallents; Mr. G. E. Tonge; Mr. Hugh A. Warren, and Miss Anna Zinkeisen; with Dr. K. W. Luckhurst (Secretary); Mr. G. E. Mercer (Deputy Secretary), and Mr. J. S. Skidmore (Assistant Secretary).

ELECTIONS

The following candidates were duly elected Fellows of the Society:

Cartier, Jean Jacques, London.
Cocker, Professor Wesley, Ph.D., Sc.D., Dublin, Eire.
Conwell, Robert MacDonald, M.S.I.A., Prestbury, Cheshire.
Dalal, Umprasad Shankerlal, Maninagar, Ahmedabad, India.
Deakin, Sydney, Newcastle-upon-Tyne, Northumberland.
Deering, Ernest Charles, B.Sc., F.R.I.C., F.I.M., Enfield, Middlesex.
Elphick, Stephen William, London.
Farrant, George Stanley, London.
Fountaine, Peter John, Tring, Herts.
France, Miss Madeleine, Wembley, Middlesex.
Girling, William Hasell, M.S.I.A., Spratton, Northants.
Goldberg, Isaac Walter, London.
Hodgkinson, Leonard Ford, Auckland, New Zealand.
Hull, James, L.S.I.A., London.
Krishna, Ayyangar Sahasranam, B.Sc., A.R.C.S.T., Bombay, India.
Lawrence, Thomas Henry, Durban, Natal, South Africa.
Meakins, Frederick James, London.
Moss, Walter Charles, B.Sc., A.M.I.H.V.E., M.Inst.F., Bromley, Kent.
Saftich, Jack Angel, Sydney, New South Wales, Australia.
Shelton, Harold Vincent, London.
Simons, Elkan, London.
Sterne, Mrs. Dahli, New York, U.S.A.
Teo, Peo Seng, Singapore.
Thomson, John Tennahill, D.A., Glasgow.
Tracy, Walter, M.S.I.A., London.
Turnbull, Robert, Bury, Lancs.
Vernon, James, B.Sc., Ph.D., Sydney, New South Wales, Australia.

Warde, Mrs. Beatrice, Epsom, Surrey.
Weinstein, Marcus Emanuel, B.Sc., Stanmore, Middlesex.
West, Ralph Leighton, B.Sc., London.
Wickham, Miss Stella Jean, M.A., South Croydon, Surrey.

CHAIRMAN OF COUNCIL 1958–9

Sir Alfred Bossom, Bt., M.P., was nominated to serve as Chairman for a further year.

BALLOTING LIST

The Balloting List for the new Council was prepared for the Annual General Meeting.

ANNUAL GENERAL MEETING

It was decided that the Annual General Meeting should be held on Wednesday, 25th June, at 3 p.m.

OTHER BUSINESS

A quantity of financial and other business was transacted.

INDUSTRIAL ART BURSARIES EXHIBITION

The Exhibition of winning and commended designs submitted in the 1957 Industrial Art Bursaries Competition was opened at the Society's House by SIR JOHN MAUD, G.C.B., C.B.E., on Tuesday, 6th May.

Welcoming Sir John, SIR ERNEST GOODALE, C.B.E., M.C., Chairman of the Industrial Art Bursaries Board, said:

We are all very grateful to Sir John Maud for coming, in the middle of his very busy day, to open this Exhibition. Sir John, who (as you all know) is now permanent head of the Ministry of Fuel and Power, can claim also to being seen occasionally on television on Sunday afternoons—when I greatly enjoy his position as a Daniel among the lions! He was, of course, formerly the permanent head of the Ministry of Education, and I think it was when he was there and I was a member of the Council of the Royal College of Art that I first met him. I have enjoyed his friendship ever since.

In spite of his translation to another sphere, Sir John has a direct contact with this exhibition, as we have a section for domestic solid-fuel-burning appliances; but in any case, he has retained his love of aesthetics and the work that he used to encourage us all to do when he was at the Ministry of Education. It is in that spirit of critical appreciation that he has come here to open this Exhibition to-day.

SIR JOHN MAUD *then spoke as follows:*

Sir Ernest has politely but rightly indicated that I have small qualification for performing this function this morning. The only direct link between this Exhibition and the Ministry of Fuel and Power where I work is something of whose

name none of us can feel proud—the 'domestic solid-fuel-burning appliance'. What a scandalous name! All praise to you for your efforts to improve the appearance of the object, but can't someone find a better name for it? That I know is not your business, and on what you have made it your business to do since you instituted these Competitions twelve years ago I want most warmly to congratulate the Royal Society of Arts.

If we go back twelve years we can, I think, imagine Britain as being in a state not altogether different from that of our original ancestors when they emerged from the Garden of Eden. By the sacrifices she had made in two World Wars our country found herself excluded from that position of easy, unchallenged superiority which she had enjoyed for much of the nineteenth century. She had shed the innocence of effortless industrial leadership. She accepted the challenge of winning a new kind of leadership in the world of international trade—and there is much to be said for finding oneself in that position. When Adam and Eve first found themselves so placed, on their exclusion from Eden, they would no doubt have disagreed with a Prime Minister who told them that 'they had never had it so good'. But I suggest that they would have been wrong, for it was at that moment when they had first tasted the fruit of the tree of Knowledge that they started out on their exciting, industrious, inventive way. They became the first of all designers. Their eyes were opened (if you remember the story); they saw that they were naked; they sewed fig leaves and made themselves aprons (you can decide for yourselves whether the 'dress textiles' or the 'women's fashion' section of the present Exhibition can claim the distinction of being first in the field). From that time onwards the growth of knowledge has constantly presented new opportunities to the designer.

Britain in these twelve years since the war has shown in two directions her capacity to excel and achieve new kinds of distinction in the world: in science and technology on the one hand, nuclear power being only the most dramatic example from among many that could be given, and on the other hand in the field of the Fine Arts. During this period not only have our engineers and scientists given us a leading position as we move into the nuclear age but we have also witnessed a burst of creative activity among the artists which has distinguished this post-war period, I believe, from any other twelve years since the Industrial Revolution began. This latter achievement at least gave one member of the House of Lords in a recent Debate the opportunity of boasting—and boasting plausibly—that though this country's record in athletics, at Wimbledon and Henley, might strike their Lordships as rather disappointing, we had to-day the best sculptor, the best musician, the best actor, and the best dancer in the world (he wisely did not mention names, and there is no need for me to do so in such company as this).

But we have had one serious trouble to deal with, the unfortunate tradition which has kept 'technics' separate from 'art'. Industrialists throughout the nineteenth and early twentieth centuries did not ally themselves with artists as they developed new industrial techniques. Our universities, and particularly the ancient ones, regarded applied science as outside their field and left it to the technical colleges. This very day there is a danger that in our new-found (and wise) determination to have more scientists and engineers we may distort our values and forget to develop the arts in partnership and alliance with the sciences. That is what makes so specially important what the Royal Society of Arts has done in many ways and particularly in holding these Competitions for industrial artists.

For these Competitions bring together increasing numbers of industrialists, colleges and artists. They reconcile three kinds of people who all need each

other. Around us is the fruit of that reconciliation. This year more than 420 candidates, representing some 70 colleges and schools, have competed in seventeen fields of industry, two of them (packaging and typography) for the first time in such a competition. In 1958 there will be at least one newcomer (watches and clocks) and I hope still more candidates, colleges and industries to enrich the Competition. So here we have a serious effort to help bring those together who should never have been separated and fight the tradition which divorces art from technics.

And these competitions do something else of great importance. They stand for the ideal of the all-round man. They encourage the emergence of the man of parts who is more than a specialist in either art or industry, and it is this sort of man who has most to contribute, I believe, both to our civilization and to our export drive. 'The peach was once a bitter almond; cauliflower is nothing but cabbage with a college education.' What Mark Twain once wrote is true enough, but the trouble in applying the truth to human education is the difficulty of knowing what kind of cauliflower the human cabbage is meant to be. Certainly the designer that we need is a man of *many* talents, capable of creative work in company with engineers and salesmen as well as artists, and that is the sort of man these Competitions are designed to discover.

To fight insularity is the other purpose of these Competitions. We all know that 'no man is an island entire of itself', but it is equally true that no island is a culture entire of itself. Certainly we in this island have reason to act accordingly—and there will be all the more need for us to know the Continent (and speak its languages) when this country becomes part of a European free trade area. So it is excellent that the designers who are successful in these Competitions should have as their reward the chance to take wing and see what is being done by designers overseas and themselves act ambassadorially abroad. The reports which winners of awards last year have written about their experiences in Italy and other countries are there for you to read as part of the Exhibition, Ladies and Gentlemen—and they will make your mouths water.

The President of the Royal Academy recently described the present Exhibition at Burlington House as 'a cross-section of all that is being seriously done in the art world'. Those words would not describe the Exhibition which opens here this morning. Here you see a *top* section, not a cross-section; for nothing is shown here which has not been picked out by those best qualified to set a standard in their respective fields—those distinguished men and women who have put us all in their debt by sparing time and tissue as members of the judging juries. These jurors are very frank in their reports. In the wall-paper section, for example, they made no recommendation this year for a bursary because they thought the standard of achievement was not high enough. Commenting, again, on one candidate's layout for a book on Georgian architecture they found the design more appropriate for 'a book of bastard Bauhaus'. It is excellent that the standard set should be a high one and that poor work should not be put on exhibition; we here would probably agree that in many lines of business our design standards are still far too low. But we can also certainly agree, from the evidence of these same jurors, that the standard has risen this year at many points—in jewellery, for example, plastics and 'Perspex'.

More than one of the juries made a point which in conclusion I would like to stress. They criticized the candidates for lack of discipline—as they politely put it, for 'not co-operating with the requirements of the test'; and they rightly pointed out that employers could be expected to be even more stringent in their criticism than examiners. You may remember Milton's description of one designer, Satan: 'The will and high permission of all-ruling Heaven left him

at large to his own dark designs.' And there is William Cowper's splendid description of the designer God:

Deep in unfathomable mines
Of never failing skill
He treasures up his bright designs,
And works his sovereign Will.

Well, the budding designer can claim no sovereign rights, nor to be left at large. It may well be that the customer is not always right, but the designer must at least pay some respect to his employer's wishes.

Sir Ernest, I thank you warmly for the honour done me by your invitation to be here this morning. I ask you to accept my warm congratulations to the Royal Society of Arts and to the winning candidates in this Competition and, on behalf of all of us, our warm thanks to the men and women of the Juries. I have great pleasure in declaring this Exhibition open.

SIR ALFRED BOSSOM, BT., LL.D., F.R.I.B.A., J.P., M.P., *Chairman of Council of the Society, then said:*

Sir John asked what sort of a cauliflower he is: well, if he, as a leading civil servant, is a cauliflower, I hope we have a lot more of them! He spoke of the Garden of Eden: on Sunday I, too, was reading my Bible, but it was the Breeches Bible. There it said Adam and Eve had their eyes opened and they went and got fig leaves and sewed themselves breeches: they had not only aprons but breeches! Sir John mentioned the benefit that comes to the young designer from travel and observation. How exceedingly correct he is! Visitors to the Brussels Exhibition will see that we, of Great Britain, are leading to-day in speed, in the air, on the sea, and on the land; records never held before by any other country. But they will also see from the exhibits and the various national pavilions that competition in the world to-day is keener than it has ever been before. Needless to say, we want our people to get the full share of the benefits that their skill has won, and can win, for them, and it is Competitions like these Bursary Contests, of which you see the results on these screens, which are going to help greatly in that way. We are delighted that Sir John has come to open the Exhibition. We sincerely thank him and hope he will come again.

A vote of thanks to Sir John Maud having been passed with acclamation, the formal proceedings then ended.

After the opening of the Exhibition, Sir John Maud was entertained at luncheon by members of Council of the Society.

The Exhibition was on view at the Society's House until 23rd May. It will be shown at the High Wycombe College of Further Education from 26th June to 11th July; at the Manchester Regional College of Art from 22nd September to 3rd October; at the Stoke-on-Trent College of Art from 13th to 24th October; at the City of Kingston-upon-Hull Regional College of Art and Crafts from 3rd to 14th November; at the Newcastle-under-Lyme School of Art and Crafts from 24th November to 5th December; at the Carlisle College of Art from 15th December to 3rd January, 1959; and at the Belfast College of Art from 19th to 31st January, 1959.

ROCKET PROPULSION

A paper by

J. E. P. DUNNING, M.A., F.R.Ae.S.,

Chief Superintendent, Royal Aircraft Establishment, Westcott, *read to the Society on Wednesday, 19th February, 1958, with Patrick Moore, F.R.A.S., in the Chair*

THE CHAIRMAN: One of the most topical subjects of the moment is that of rocket propulsion. It is difficult to open a daily paper these days without reading about some new development. And I think this is one of the troubles encountered by the non-specialist: so much is written and also said that it is very difficult for him to get at the truth of what really is going on. We know that there are tremendous advances being made all the time; yet we must also remember that they all have a common basis, and before we progress in understanding we need to find out what that basis is. It is for this reason that this afternoon's lecture is going to be of such interest. The government centre for rocket research in Britain is at Westcott, and who is more qualified to tell us about rocket propulsion than the Chief Superintendent of the Royal Aircraft Establishment there? I am sure that you all know Mr. Dunning by repute. Before he came to Westcott he was at Farnborough, and then spent five years at the Ministry of Supply Headquarters, working upon methods of propulsion such as ram jets and rockets.

The following paper, which was illustrated by lantern slides and demonstrations, was then read.

THE PAPER

INTRODUCTION

It was the original wish of the Society to have a lecture entitled 'Rocket Propulsion and Interplanetary Flight'. This is an extremely broad, and one may say even spacious topic, of which the first part may be treated as established fact and the latter as an achievement yet to be realized, for which rocket propulsion will be a pre-requisite. It was agreed that I should confine my remarks to rocket propulsion, but I must admit that it is not without some qualms that I am attempting to give this lecture. Since that significant date, 4th October, 1957, when the Russians launched the first man-made satellite, the World has become 'rocket conscious', and so much fact and speculation have been published that in preparing this talk I began to wonder what was left for me to say. You will appreciate that it is not possible to talk about specific rocket developments, nor do I think such a course desirable.

We are all fully aware of the psychological impact which the successful launching of the first satellite had upon the World. It was a surprise to most of us, but at least to some it should not have been so. The Russians had openly declared their intentions, and to give one instance, of which I personally am aware, Petrov of the Soviet Institute of Sciences stated in July of last year at

the College of Aeronautics, Cranfield, that it was their intention to launch a satellite into a 'near-polar' orbit during October or November. Nevertheless, when it happened we were surprised. Naturally, satellites and their orbits became a polite topic of conversation, and the enthusiastic advocates of space flight acquired an aura of respectability. Perhaps some of us, having in mind certain alleged statements, began to seek the precise meaning of 'utter bilge', but to me the major effect of Sputnik I was salutary. Once more I began to marvel at the powers of observation and deduction of Kepler and Newton and, in the parlance of a B.B.C. Panel Game, decided to have a 're-cap' on First Principles.

If you will accept my contention that First Principles constitute the 'art' of scientific and technical development, then my proposed theme will not be inappropriate and this talk has been based on the self-imposed task of 're-capping'. A discipline for me, I trust it will be of some interest to you, and that at its conclusion you will not accuse me of sadistic tendencies.

DEFINITIONS

Not many months ago I said that rocket propulsion was the most vivid tangible expression of Newton's Laws of Motion. Perhaps this is not so apparent to the layman; therefore I wish first of all to define a rocket and then illustrate my definition by some simple examples. In speaking of definitions I am reminded that at school I was taught that 'the logarithm of a number to the base e is the index of the power to which e must be raised to produce that number'. Yet later, at a higher seat of learning, the preferred definition was

$$\log x = \int \frac{dx}{x}$$

Both definitions are correct, but they create two different appreciations of the meaning of logarithms. Therefore in defining a rocket as 'a device which propels itself solely by the ejection of a portion of its own mass in a direction opposite to that in which motion is desired', I realize that I am creating a mental picture which will direct subsequent reasoning along a particular channel.

Having talked about a vivid tangible expression it is incumbent upon me to justify my definition by a simple illustration. On one occasion I asked my audience to imagine a man sitting on a perfectly smooth level table and posed the question 'How does he get off?' Without too long a pause, which was just as well (as I found subsequently), I supplied the answer. The man takes off his jacket and throws it away. Immediately he starts to slide off the table in the direction opposite to that in which he has thrown his jacket. The complete system of the man and his jacket constitute a rocket. My audience made me realize that my illustration had an inherent weakness, because I called upon them to visualize something which was not demonstrable, namely a perfectly smooth table. This does not detract from the value of my definition, but perhaps a better illustration is with a child's balloon. The balloon together with the air it contains is a single system, and if the vent is opened when the balloon is free from restraint,

it will travel in the direction opposite to that in which the air is ejected from the vent. Truly it is a rocket. Are we not now justified in giving to the Montgolfier brothers the credit for staging the first rocket propelled flight in which animals were carried? In the grounds of Versailles on 19th September, 1783, the brothers performed their second experiment with a fire balloon carrying aloft a sheep, a cock, and a duck. The initial upward motion of the balloon, and I must stress initial, was due to the ejection of hot air, and therefore it was acting as a rocket. History records that the animals returned to Earth with only minor damage being suffered. The sheep kicked the cock.

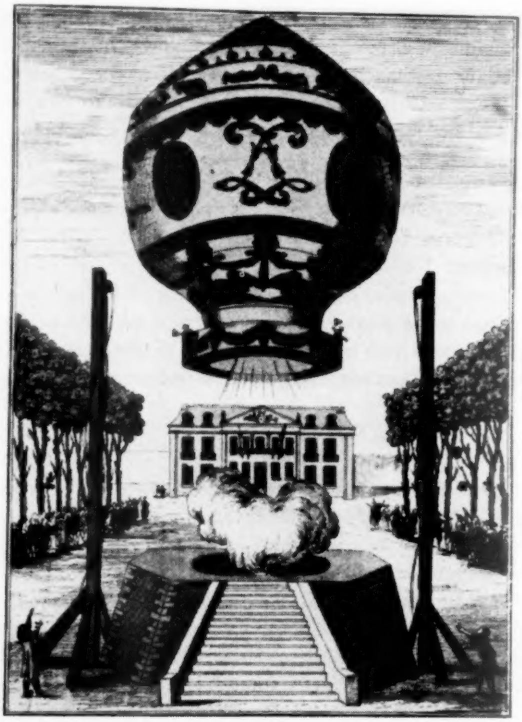


FIGURE 1. *The Montgolfier Brothers' balloon*

In quoting this exploit of 1783 I have no wish to detract from the achievement of the Russians, but definitions, like statistics, may be made to prove anything.

FIRST PRINCIPLES

In order to achieve some semblance of continuity in this talk, what mathematics I have had to use are placed in an Appendix. All of it may be found in textbooks, but piecing it together constituted a useful part of my 're-capping' exercise.

Equation I of the Appendix is

$$v = \bar{V} \log \frac{M_1}{M_2} \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \text{(I)}$$

where $\bar{V}$ is the velocity with which mass is ejected from the body, relative to the body.

M_1 is the mass of the body (rocket) when it was initially at rest.

M_2 is the mass of the body (rocket) when it has acquired a velocity v.

This expression is free from the complications introduced by allowing for gravitational forces and aerodynamic drag. Nevertheless, it contains the essential criteria for our study of rocket propulsion.

Considering first the criterion $\bar{V}$, the Appendix shows that it is a measure of the 'Specific Thrust' of the rocket which is defined as the thrust divided by the rate of propellent consumption. If the thrust is expressed in pounds weight and the propellent consumption in pounds mass per second

$$\text{Specific Thrust, I} = \frac{\bar{V}}{g} \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \text{(III)}$$

which has the dimensions of time.

Workers in the rocket field frequently use the expression 'Specific Impulse', which is numerically identical with specific thrust, but the derivation indicates that the latter term is the more correct. It is really nothing more than the inverse of 'specific fuel consumption', the important index of performance in the more orthodox fields of propulsion.

As in all fields of propulsion, the aim of scientists and rocket engineers is to obtain better performance, and clearly the greatest possible value of $\bar{V}$ is desired. So far I have spoken only of the ejection of mass and not considered what form that mass should take. Nor have I yet considered the source from which energy is derived to eject that mass. Let us revert to the two illustrations of a rocket, the man discarding his jacket and the child's balloon. In the former case the man expends energy in throwing away his jacket and at the instant of discard gives himself an impulse, the magnitude of which is determined by the velocity he imparts to the jacket and by its mass. The word 'impulse' implies something sudden and, in fact, the man does sense one short push. If he wishes to increase his velocity he will have to discard another article of apparel and apart from our doubts about the propriety of this process, we may say that it will be a jerky one. With the balloon, it is clear that some measure of continuity and gradualness exists and that it receives a push so long as air is ejected. We may say now that the ejection of the mass of a rocket (its propellent) in the form of a gas is the most efficient and practicable system. In fact, it will become apparent as my talk proceeds that a gas provides the *only* practicable system.

In Section 3 of the Appendix equation IV is derived, giving

$$v_2 = \left[2g \left(\frac{\gamma}{\gamma - 1}\right) \frac{R}{M} \cdot T_1 \left[1 - \left(\frac{P_2}{P_1}\right)^{\frac{\gamma - 1}{\gamma}} \right] \right]^{\frac{1}{2}} \quad \ldots \quad \text{(IV)}$$

where v_2 is the velocity acquired by a gas flowing in an ideal manner, without friction, without loss of heat and without shock (i.e., isentropically) from stagnant conditions in a chamber maintained at pressure P_1 and temperature T_1 to a chamber maintained at pressure P_2. If we consider some of the constituent quantities in the above expression some appreciation will be gained of what is desirable in a rocket.

The Total Heat per unit mass of the gas is K_pT_1, and this is given as

$$\left(\frac{\gamma}{\gamma - 1}\right) \frac{R}{M} \cdot T_1$$

where K_p is the specific heat of the gas at constant pressure. Clearly the Total Heat imparted to the gas within the first chamber should be as large as possible, but equation IV permits us to express this in a different way. We wish the term $\frac{\gamma}{\gamma - 1}$ to be as large as possible and this implies that γ should have a value near unity. It indicates that we should use diatomic or tristomic gases in preference to those of monatomic structure. We know also from the Quantum theory that the specific heats of gases increase with increasing temperature and therefore γ diminishes. This is beneficial in that for a given quantity of Total Heat, the temperature T_1 is lower than would otherwise be the case, but without regard for practical limitations a high value of T_1 is desirable. It is evident also that we desire to have as low a value as possible for the molecular weight M.

Finally, the pressure ratio $\frac{P_1}{P_2}$ should be as large as possible.

At first sight one may consider that there is no limit to what we make the value of v_2, merely by our choice of gas, temperature and pressure ratio. However, before examining some of the physical, chemical and engineering limitations, I should like to revert to the important assumption that the gases expand from one chamber to another without loss. In the first chamber, the combustion chamber of the rocket, the gas is stagnant and all the realizable energy is manifest as Total Heat. In expanding into the second chamber, in practice the ambient atmosphere or space, the energy of the gas is redistributed and it acquires

kinetic energy. In Section 3 of the Appendix equation IV is reshaped to give equation (V)

$$\frac{v_2^2}{2g} = K_p T_1 \left[1 - \left(\frac{P_2}{P_1}\right)^{\frac{\gamma - 1}{\gamma}} \right] \quad \ldots \quad \ldots \quad \ldots \quad (V)$$

and this shows immediately that the term

$$\left[1 - \left(\frac{P_2}{P_1}\right)^{\frac{\gamma - 1}{\gamma}} \right]$$

determines what fraction of the Total Heat is realizable as kinetic energy. Because v_2 is to be as high as possible we are implying that it must be supersonic and Section 4 of the Appendix shows how this is achieved. The gas in issuing from the first chamber must accelerate in a convergent passage, acquiring the local velocity of sound at the end of the convergence, and then continue accelerating to supersonic speed in a divergent passage. Supersonic speed will be achieved only if the pressure ratio $\frac{P_1}{P_2}$ exceeds the value

$$\left(\frac{\gamma + 1}{2}\right)^{\frac{\gamma}{\gamma - 1}}$$

Thus in stressing that v_2 should be as great as possible we automatically specify a minimum operating pressure ratio, the Critical Pressure Ratio, and demand also a convergent-divergent nozzle. A Laval nozzle, as it is often called, is a characteristic feature of a rocket, and a picture familiar to all those who work on rockets is the exhaust jet with its typical shock diamonds, indicating that the flow of gas emerging from the nozzle is supersonic.

In the foregoing it is stated that the greater the design pressure ratio $\frac{P_1}{P_2}$ the greater is the fraction of the Total Heat which is realized as kinetic energy. The curve in Figure 3 illustrates how the specific thrust varies with design pressure ratio for a constant value of Total Heat. To obtain the benefits accruing from increasing the design pressure ratio, the propelling nozzle of the rocket must increase in size, or more correctly the area of the exit plane of the nozzle must increase if the throat area is maintained constant. To reach the 149 per cent indicated in Figure 3, the exit area of the nozzle must be infinitely large.

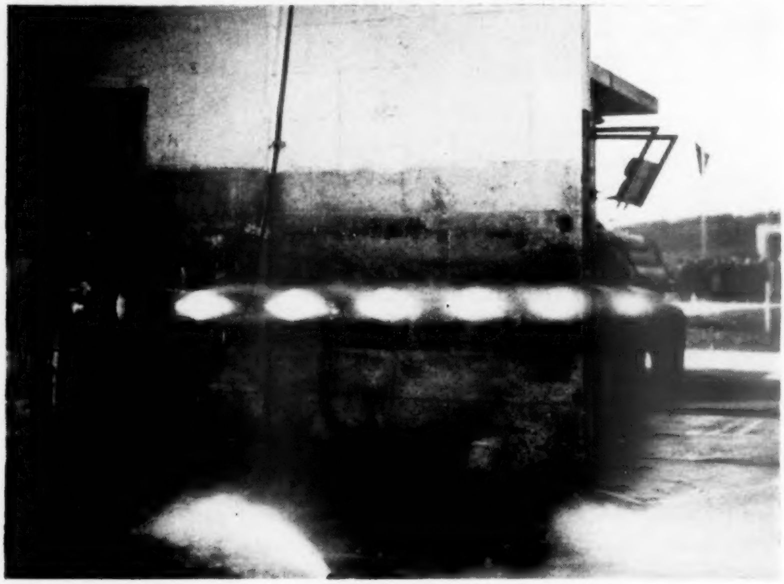


FIGURE 2. *Rocket jet showing shock diamonds*

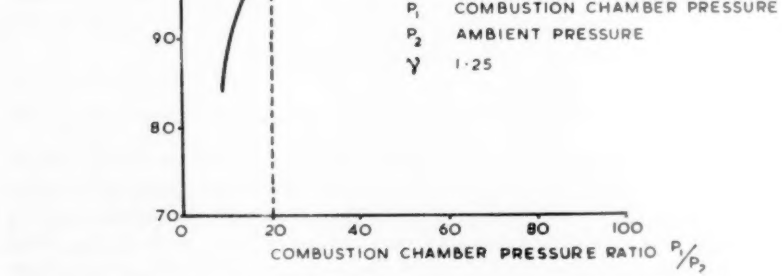


FIGURE 3. *The effect of combustion chamber pressure ratio on specific thrust (variable nozzle expanding to ambient pressure)*

We can visualize a nozzle having a variable exit area, but purely practical considerations will impose limitations on the degree of variability. Therefore, at some stage in the flight of a rocket propelled vehicle from the Earth's surface to high altitudes the nozzle will cease to expand the gases fully to the ambient pressure. On leaving the exit plane of the nozzle the gases will continue to expand, but they do so virtually without resistance, and this unresisted expansion makes no contribution to the rocket thrust. However, because the pressure level in the exit plane of the nozzle is greater than the ambient pressure, there is an additional thrust term equal to the product of the pressure differential and the area of the cross-section of the exit plane of the nozzle. This is explained fully in Section 5 of the Appendix, and the curves in Figure 4 illustrate the thrust increments obtained as the altitude is increased from sea level to 100,000 feet.

The thrust increments are shown for four pressure ratios, with the nozzles designed for sea level operation. The expression from which these curves are deduced, equation (VI) of the Appendix is

$$\frac{\Delta I}{I_D} = \left(\frac{\gamma - 1}{2\gamma}\right) \frac{\left[1 - \frac{P_0}{P_2}\right]}{\left[\left(\frac{P_1}{P_2}\right)^{\frac{\gamma-1}{\gamma}} - 1\right]} \quad \ldots \quad \ldots \quad \ldots \quad \text{(VI)}$$

from which it is clear that the greater the design pressure ratio $\frac{P_1}{P_2}$, the smaller is the percentage increment of thrust with increase of altitude. It is clear also that at a particular altitude the percentage increment of thrust is a constant fraction of the maximum possible increment (when $P_0 = O$), whatever the design pressure ratio. At 100,000 ft. altitude the ratio $\frac{P_0}{P_2}$ is 0·01 if P_2 is the sea level pressure. Therefore, the thrust increment at this altitude is 99 per cent of the maximum attainable and the total thrust must therefore be greater than 99 per cent of the maximum attainable. In fact, if the design pressure ratio is 30 : 1 or greater, the total thrust at 100,000 ft. altitude is greater than 99.9 per cent of the maximum attainable. If then we wish to define where the Earth's atmosphere ends and 'Space' begins in terms of rocket performance we may, quite arbitrarily, suggest 100,000 ft. altitude. It is a nice round figure, but I must admit that this suggestion does not look quite so elegant if the altitude is expressed in kilometres.

Reverting to the comment that the greater the design pressure ratio the smaller is the percentage increment of thrust with increase of altitude, it should be noted that this differential never permits the intrinsic benefit from increasing the design pressure ratio to be surpassed. Solely on the score of high specific

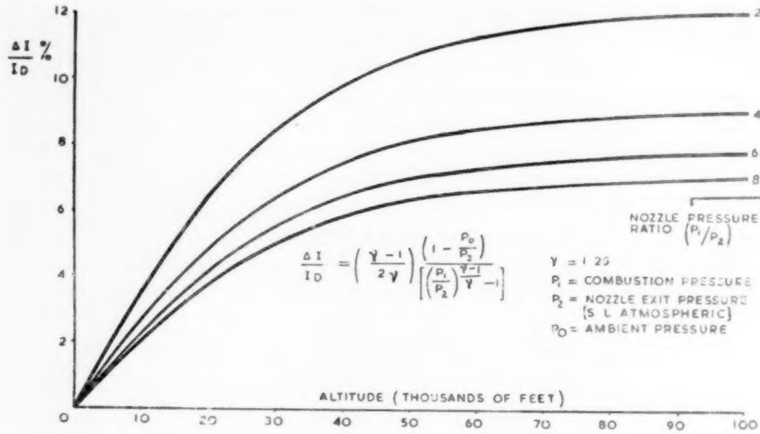


FIGURE 4. *Percentage increase of specific thrust with respect to altitude (nozzle designed for sea level conditions)*

thrust, the higher the design pressure ratio the better, but high specific thrust is not the only significant design criterion; weight also is important, as equation I indicates. It is of no avail if we increase the temperature T_1, reduce the molecular weight M and increase the pressure ratio $\frac{P_1}{P_2}$ if at the same time we incur a weight penalty which reduces the value of $\log \frac{M_1}{M_2}$ to offset the increase in $\bar{V}$.

Although many of us may be accused of developing rockets merely because of our interest in difficult scientific and engineering problems, it is quite evident that our financial backers are hoping for a 'useful' application. In other words, a rocket is to be used to carry something to somewhere. This 'something' we call the payload and M_1 comprises the payload, the propellent and the rocket device itself with the associated structure. In the course of the powered flight when the propellent is expended we reduce the weight to M_2. Therefore, the greater the weight of propellent in relation to M_1, the greater is the velocity acquired by the rocket. Likewise, the smaller the payload for given structure and propellent weights, the greater is the acquired velocity. It should be noted that according to equation I the velocity acquired is apparently independent of the manner in which M_1 is reduced to M_2, provided the ejected mass acquires a velocity $\bar{V}$ relative to the rocket. However, as the Appendix shows, for a given value of $\bar{V}$ the thrust of the rocket is determined by the rate of ejection of mass. The lower the rate of ejection the lower is the thrust, but for a given initial mass of propellent the longer is the thrust sustained and the 'Impulse' is constant. It has become accepted practice to designate this 'Impulse' as 'Total Impulse'

to provide a clear distinction from the misnomer 'Specific Impulse'. Expressed mathematically,

$$\text{Total Impulse} = \int_0^t F dt$$

where t is the duration of thrust

$$\text{F is the thrust} = -\bar{V}\frac{dm}{dt}$$

where $-\frac{dm}{dt}$ is the rate of reduction of mass.

Now the manner in which this Total Impulse is utilized depends on the intended application of the rocket. If it is to be used in one glorious burst as when the man discards his jacket, the thrust is large, but of short duration. The stress to which the body is subjected is determined, to the first approximation, solely by the magnitude of the thrust applied. Therefore, the higher the thrust the greater is the strength required in the structure if a given stress is not to be exceeded. Apart from allowances for ingenuity in design, a greater thrust implies a greater structural weight and hence a reduced value of $\frac{M_1}{M_2}$. Thus implicitly equation I includes an allowance for the manner in which M_1 is reduced to M_2.

I introduced this discussion on weight by referring to the possible reduction in the value of $\log\frac{M_1}{M_2}$ in striving for the highest possible values of $\bar{V}$. Total Impulse and Thrust have now been introduced as significant performance criteria. Total Impulse cannot be disentangled from $\bar{V}$ and $\log\frac{M_1}{M_2}$, but we may, within limits, discuss quite independently the effect of Thrust on weight. For the sake of argument let it be assumed that a rocket propelled vehicle has been specified and the only design choice left to be made is in the number of rocket engines to employ to achieve the specified thrust. In other words the number 'n' of engines, each of thrust $\frac{F}{n}$ to achieve a thrust F has to be selected. On these premises, which imply no variation of propellent specific thrust with variation in engine size, the choice of 'n' will be decided primarily from considerations of weight.

It will be sufficient and avoid elaborate detail to consider the weight of a complete rocket engine as some factor of the weight of its major component, the combustion chamber together with the propelling nozzle. This component is a pressure vessel designed to withstand a given hoop stress. If the size of engine is varied by geometrical scale and L is a typical linear dimension, the thrust will be proportional to L^2 and the weight proportional to L^3. The specific weight of the engine will then be proportional to size, expressed as a linear dimension.

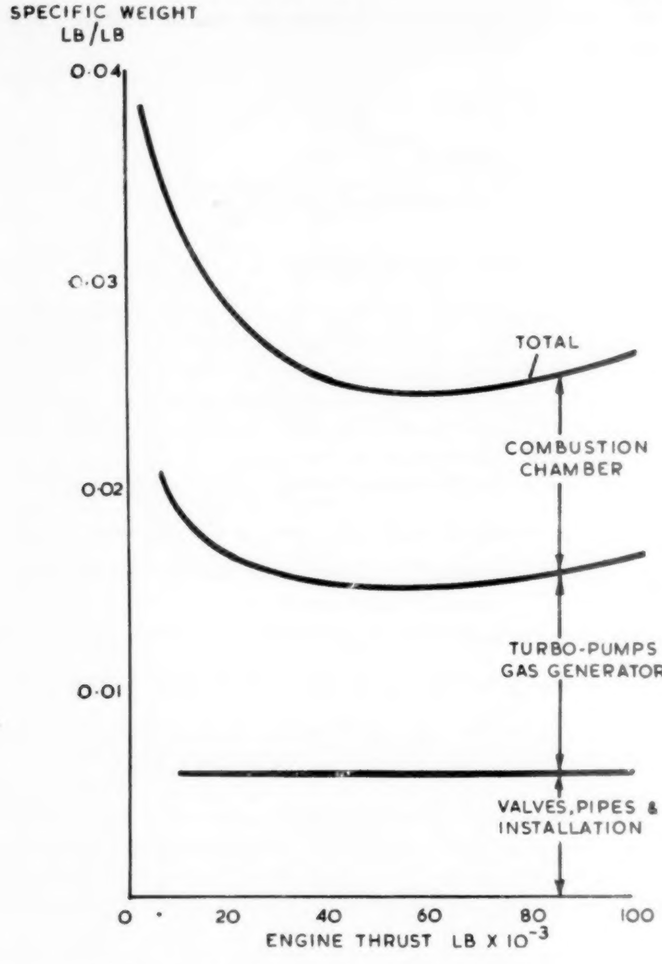


FIGURE 5. *Variation of engine specific weight with size*

This is our old friend the Square-Cube Law. Carried to extremes this implies that 'n' should be infinitely large and that each engine should provide an infinitely small thrust. This somewhat idealized argument has brought us to a ridiculous conclusion, but what are the worth while conclusions? The first is that 'the bigger the better' is not true. Nowadays no one would buy a car with an engine having one big cylinder. Perhaps two cylinders, but more likely four or six. The second conclusion is that somewhere in the thrust scale we can build a rocket engine of minimum specific weight. In the low thrust range practical

limitations on component sizes will necessitate departures from geometrical scaling, thus imposing a weight penalty. In the high thrust range the designs will approximate towards the Square-Cube Law. Therefore a curve of Specific Weight *v.* Thrust must have a minimum. Baxter[1] has indicated how, in his opinion, specific weight varies with thrust, and his curve is given in Figure 5. Although I do not necessarily accept the form of the curve given by Baxter, it does support my general argument that somewhere in the thrust scale we do obtain a rocket engine of minimum specific weight.

Some indication has been given that the realization of high specific thrust must incur a weight penalty. Therefore it is a basic design requirement to know how specific thrust and weight are inter-related. In Section 6 of the Appendix the relationship between small changes in engine weight and small changes in specific thrust is given by

$$\frac{dM_E}{M_E} = \frac{M_1 M_2}{M_p M_E} \log_e \frac{M_1}{M_2} \cdot \frac{dI}{I} \quad \ldots \quad \ldots \quad \ldots \quad \text{(VIII)}$$

where M_E is the weight of the engine

M_p is the weight of the propellents.

As would be expected, the greater the ratio $\frac{M_1}{M_2}$ the less sensitive is the performance to changes in engine weight.

It is perhaps of some interest to examine the German V.2 missile from this aspect. The relative weight figures are given in the Appendix and it is deduced that an 8 per cent change in engine weight is equivalent to 1 per cent change in specific thrust. It is not my wish to elaborate on the significance of these figures, but I would stress that a knowledge of this inter-relationship is essential to a rocket engine designer if he is to keep his development problems in their right perspective. It shows how the ultimate requirements of a rocket engine affect its design, and to this we may account the tendency to have 'custom built' engines for particular applications. This is a natural corollary from striving always for the ideal, but it does lead to a multiplicity of designs and high development costs. In fact, as is common amongst scientists and engineers, we have probably been guilty on occasions of sacrificing the 'Good' for the 'Better', and thereby failed in our efforts to raise the standard of the 'Good'. Once more I must be excused from elaborating on this theme, and conclude this particular section of my talk by saying that as long as we develop rocket engines, and whatever be the relative significance of specific thrust and weight, we shall be striving to increase the former and reduce the latter.

SOME PRACTICAL CONSIDERATIONS

In the early part of this talk I said that the manner of defining a rocket would direct subsequent reasoning along a particular channel. In the path taken so far I have eschewed most carefully any discussion on chemical problems, although

reference to combustion and propellents could not be avoided. Almost at the outset it was necessary to accept a gas as the only acceptable form in which to utilize the propellent, and this gas is required at high temperature and high pressure and should have a low molecular weight. Without more demur it must be said that, at least for the present, the only feasible way of creating this gas is by chemical reaction. The state of the propellents prior to the chemical reaction or combustion processes may be either liquid or solid and the choice is dependent on the application to which the rocket is to be put. For many applications there is no doubt what the choice should be, but there is a field in which the rival merits are much in balance. However, it is a good generalization to say that the choice is very much dependent on the duration for which the thrust is required. If the duration is of the order of 30 seconds or less, solid propellent is preferred, but if the duration is for one minute or more, we usually select liquid propellents. There are many factors which qualify this choice, but to deal with these now would immerse me in rocket technology which is beyond my self-imposed terms of reference.

Within the limits of this talk, it is more convenient to discuss the characteristics of some liquid propellents, but before doing so it is considered desirable to mention some of the design criteria of a solid propellent unit.

Cordite, a generic title for many present-day solid propellents, is basically a mixture of nitro-cellulose and nitro-glycerine, but other ingredients may be incorporated to impart special characteristics and, in particular, to give specific rates of burning. The elementary constituents of this mixture are carbon, hydrogen, nitrogen and oxygen. Cordite, as do all solid propellents, burns on its exposed surface, evolving gas and continuously revealing a new surface throughout the burning process. The rate at which gas is evolved is dependent on the propellent composition, the exposed surface area and the pressure at which burning occurs. For a given composition the rocket designer is free to choose the surface area and, within limits, the burning pressure. It is necessary to say 'within limits', because all solid propellents are subject to a pressure limit below which they will not sustain combustion and also because the burning rate is dependent upon pressure. Generally,

Burning rate is proportional to $(\text{Pressure})^n$

and in some cases 'n' itself may be pressure dependent. In practice 'n' is never allowed to exceed the value 0·8. In Section 7 of the Appendix it is shown that if 'n' is unity, burning will be unstable in that it will 'run away' and the propellent will act as an explosive.

Because burning is a superficial process the designer must ensure that throughout the process the requisite area is exposed. Constant thrust is a normal requirement, and therefore constant surface area is usually demanded. For what we term a 'cigarette burning' charge this requirement is easy to meet, but for charges which have a central conduit and burn radially outwards no simple form will do. In Section 8 of the Appendix an indication is given of how suitable forms may be evolved. In essence, the developed surface of the conduit must

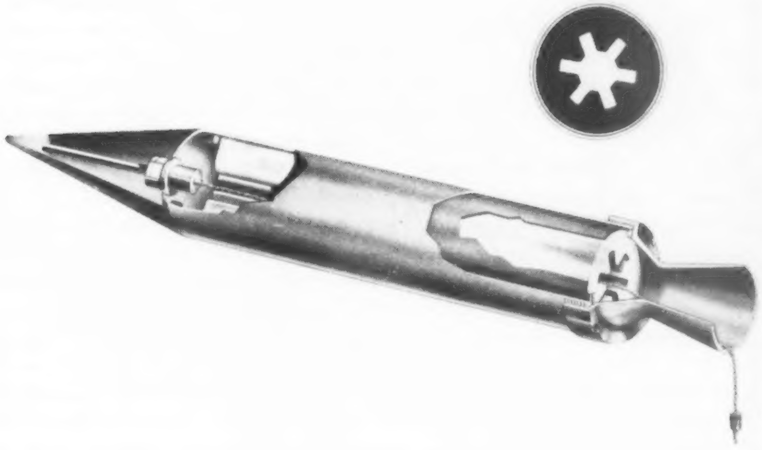


FIGURE 6. *Solid propellent rocket*

resemble a corrugated sheet, the convolutions of which are formed by semi-circular arcs. The convex and concave surfaces need not necessarily be of the same radius.

I do not propose to discuss the design of solid propellent charges in more detail, but it is hoped that sufficient indication has been given that design problems exist, some of which are elusive and some intractable. The apparent simplicity of the finished product is deceptive.

Returning now to the liquid propellents, it is necessary to say that the chemical reaction is normally created by the intimate mixing within the combustion chamber of two liquids, one the 'fuel' and the other the 'oxidant' (in the case of the solid propellent the mixing of the fuel and oxidant is made in the manufacturing process, but chemical reaction does not take place until heat is applied). The Table[2] on page 490 gives 12 possible combinations of liquid fuel and oxidant, together with the significant data on the combustion products.

The propellent combinations marked * are those already reduced to standard rocket practice in this country and in the U.S.A. It may be mentioned that the propellents such as oxygen, hydrogen and fluorine are considered to be supplied to the rocket engine in liquid form. The Germans used alcohol-oxygen in the V.2, but they did not realize the specific thrusts quoted. The operating combustion chamber pressure was only 220 lb. p.s.i. absolute, and the alcohol was diluted with water 75/25 to reduce the combustion temperature to a value acceptable to the materials used. The V.2 engine developed 56,000 lb. thrust at sea level and the specific thrust was about 203 lb./lb./sec.

Fuel	*Oxidizer*	T_1 °K	*M*	γ	*Specific Thrust* I_D *lb./lb./second* at 500 *p.s.i.a.*	at 1,000 *p.s.i.a.*
*Gasoline	Hydrogen Peroxide	2680	21	1·20	248	273
Hydrazine	Hydrogen Peroxide	2610	19	1·22	262	288
*Gasoline	Nitric Acid ...	2860	25	1·23	240	255
Aniline ...	Nitric Acid ...	2830	—	—	235	258
Ammonia	Nitric Acid ...	2350	21	1·24	237	261
*Alcohol ...	Oxygen	3090	22	1·22	259	285
*Gasoline	Oxygen	3210	22	1·24	264	290
Hydrazine	Oxygen	2980	18	1·25	280	308
Hydrogen	Oxygen	2510	9·0	1·26	364	400
Ammonia	Fluorine	4010	19	1·33	306	337
Hydrazine	Fluorine	4410	19	1·33	316	348
Hydrogen	Fluorine	2830	8·9	1·33	373	410

$\underbrace{T_1 \quad M \quad \gamma}_{\text{At 500 p.s.i.a.}}$

There are many possible propellent combinations in addition to those listed above, but it will be seen that the ratio of those reduced to standard practice (four) to the twelve listed reveals that the engineers have plenty to be getting on with before the chemists suggest any more. If the question is asked, 'Why in this year 1958 are only four propellent combinations accepted as standard?', many answers are required. To deal with them adequately, not one but a course of lectures would be necessary and at this time only a brief outline is possible.

In the first place, the history of military rocket development is comparatively short. Secondly, there must be an incentive for development, and given this incentive it must be recognized that technological progress is made in evolutionary

stages. We have to look only at the material progress of our civilization within this century to appreciate this fact. Expressed colloquially, man must learn to walk before he runs; with rocket I believe he is just emerging from the crawling stage. But what are these problems encountered in rocket development?

By their nature, oxidizers must possess objectionable characteristics. They have to react readily and energetically with the fuel, and as they are not endowed with powers of discrimination they react with many other substances as well. Most of us will have some knowledge of chemistry, at least up to matriculation standard, and remember our respect towards nitric acid which the Table lists as an oxidizer already accepted for practical use. There is a limited choice of materials compatible with nitric acid, and for constructional purposes we are virtually restricted to zinc-free aluminium alloys and certain grades of stainless steel. Hydrogen peroxide, which is used in the concentration of 80–90 per cent, is also highly selective in its range of compatible materials. Copper, lead, zinc and carbon act as catalysts, accelerating the decomposition of the peroxide into steam and oxygen, and only 99·9 per cent pure aluminium and some grades of stainless steel are suitable for long life contact. Liquid oxygen must be stored at temperatures below −183°C, and this itself creates a materials problem. At this temperature most organic materials are extremely brittle and have greatly reduced ductility and impact strength. Undressed chamois leather does retain some flexibility at the temperature of liquid oxygen, but Allen, the Chief Engineer of the Armstrong Siddeley Motor Rocket Division, once remarked, when faced with a requirement to make a flexible bag tank, 'unless someone can breed goats bigger than elephants, they are not much use to me'. Fluorine, the last of the oxidizers listed, has particularly strong toxic properties and the utmost care is needed in its use. Incidentally, the classification of fluorine as an oxidizer is merely for want of a comprehensive term to describe all the chemical reactions which occur within a rocket engine combustion chamber.

What has been said already shows that the expert services of the chemist and the metallurgist are required, but this is not all. If we look once more at the rocket engine of the V.2 missile, but as a sop to our vanity consider it somewhat improved, we shall have an engine developing say, 60,000 lb. of thrust and weighing, according to Baxter's curve (Figure 5), 1,250 lb. We may assume a specific thrust of 250 lb./lb./sec., and a combustion chamber pressure of 500 lb. p.s.i. The rate of propellent flow will be 240 lb. per second, which is about 24 gallons per second. If one is not too selfish and has some regard for the rest of the family waiting for the bathroom, one uses about this quantity of water, but the bath is not filled in one second. The roadside petrol pump fills our tanks at the rate of about six gallons per minute. In our rocket combustion chamber the two propellents are injected, atomized, vaporized and react with each other to form a gas at the rate of 240 lb. per second at a pressure of 500 lb. p.s.i. and a temperature of around 3,000°K. To add some verisimilitude to these figures it is worth while to examine what power this rocket will develop in its flight if we assume that it propels a vehicle having a mass ratio of the original V.2, which was 3·24. Just before the propellents are exhausted and thrust ceases

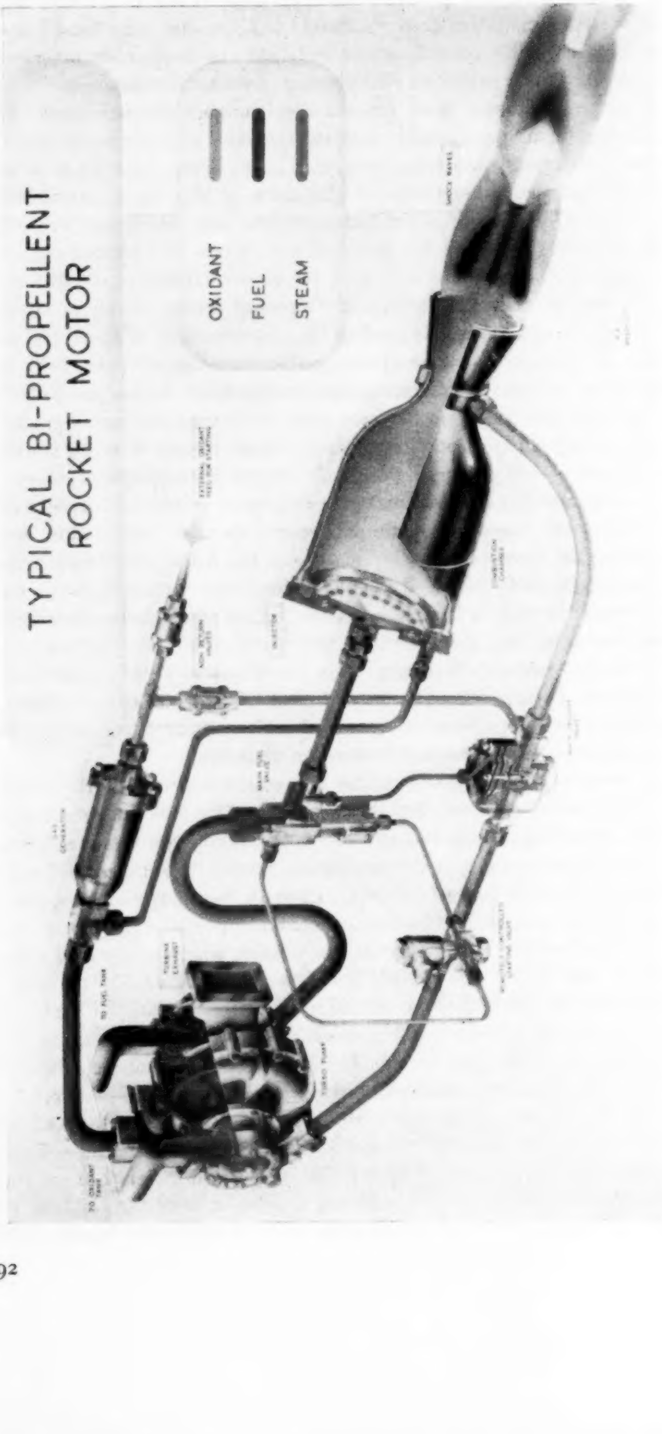


FIGURE 7. *Diagrammatic sketch of liquid bi-propellent rocket engine*

the missile will have acquired a velocity of 9,370 feet per second, and the rocket will be developing just over one million horse power. If we regard our rocket merely as a source of heat—an oil-fired furnace—then the intensity of combustion is of the order of 100 million C.H.U./cu./ft./hr./atmosphere. Whittle's first gas turbine combustion chamber was rated at about one million C.H.U./cu. ft./hr./atmosphere.

It will have been noticed that I use the term 'rocket engine', at least when talking about those devices which use liquid propellents. In the example given above it has been described as giving 60,000 lb. thrust; developing over one million horse power at a particular stage in flight and as a highly developed furnace. In fact, it is just as much an engine, as we understand the word, as are the turbine engines in the Hunters, the Comets, the Viscounts and the Britannias. Figure 7 illustrates the major components of a liquid bi-propellent rocket engine.

The engine has two pumps to transfer the propellents from their storage tanks and deliver them at 700–800 lb. p.s.i. pressure to the combustion chamber. A gas turbine developing some 1,000 horse power drives the pumps, receiving its power from gas at about 800°C, generated in a small chamber which itself operates on the main propellents. The combustion chamber has already been described as a highly developed furnace operating at 500 lb. p.s.i. and 3,000°K. Therefore it has to be strong enough to withstand this pressure and adequately cooled to maintain its strength. The physical and chemical processes within the combustion chamber result in an efflux of gas moving at about 8,000 ft. per second in a stream nearly 2 ft. diameter.

To the chemist and metallurgist already mentioned must be added the physicist, the mathematician, the engineer and the draughtsman, together with the highly specialized manufacturing facilities, if we are to realize our objective—*a rocket engine*.

WHY USE ROCKETS?

Resulting from the definition of a rocket, the term 'specific thrust' was introduced and defined as the thrust per unit mass flow rate of propellent. The frequency with which it has been mentioned and its appearance in all the calculations on performance are tokens of its importance. The specific fuel consumption of a turbo jet engine is important, but it does not carry the significance which is attached to specific thrust when dealing with rockets. Yet specific thrust is the inverse of specific fuel consumption. We now know that numerical values around 250 are typical for standard propellents in a modern rocket engine. Expressed as specific fuel consumption, this is equivalent to 14·4 lb. propellent per hour per pound of thrust. The turbine engine designer might well throw up his hands in horror. With this high consumption, why use rockets? The answer is in several parts.

1. A rocket can provide a greater thrust per unit frontal area than any other propulsion device.
2. The specific weight of a rocket with respect to thrust, neglecting the weight of propellent consumed, is less than that of any other propulsion

device. When the propellent weight is included this advantage still holds for limited durations of thrust.

3. Except for the allowance of approximately 10 per cent increase of thrust with increase of altitude from sea level to 60,000 ft. and beyond, rocket engine performance is independent of ambient conditions.

4. As a corollary to 3, a rocket is the only possible source of propulsion outside the Earth's atmosphere. It is the only possible source of propulsion within the Earth's atmosphere if flight speeds greater than Mach No. 5 are desired.

5. Also as a corollary to 3, the advantages stated in 1 and 2 are increased as the operating height increases, the ratios of the comparative values becoming infinite outside the atmosphere.

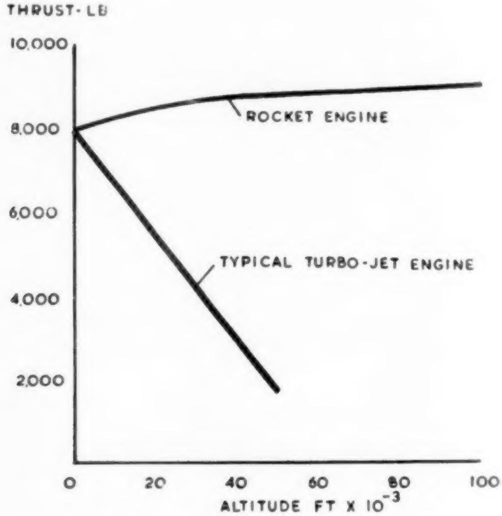


FIGURE 8. *Variation of thrust with altitude of two types of engine*

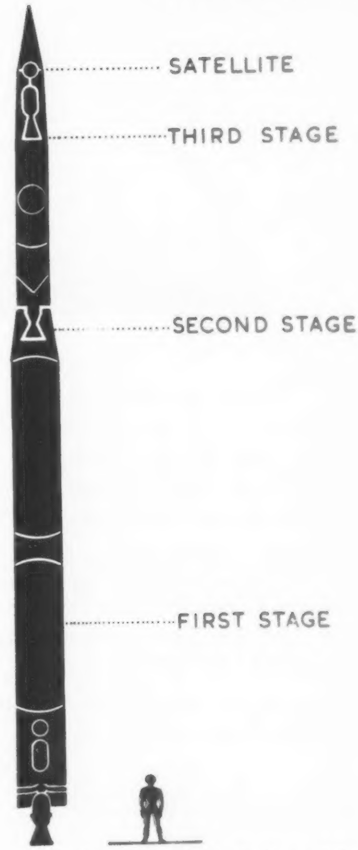
If then guided missiles are required, if satellites are required and if space flight is ever to be achieved, rockets are required. Peter Simple may ask 'Why?' but he cannot deny that their development is taxing man's ingenuity, no matter how misguided.

PRESENT LIMITATIONS AND POSSIBLE DEVELOPMENTS

It has been stated that for the present our only practicable source of energy in a rocket is from a chemical reaction. The Table listing 12 propellent combinations shows that realized values of specific thrust are around 250 lb./lb./sec. and that, in the course of time, a value of 400 lb./lb./sec. may be approached.

The minimum velocity which a body has to acquire to escape from the Earth is 36,900 ft. per second, and the velocity of a satellite travelling round the Earth in a circular orbit is, subject to some small corrections, 26,100 ft. per second. With our present day propellents, assuming no allowance for aerodynamic drag or other corrections in our simplified formula, a satellite vehicle must have a mass ratio of 25.12 : 1. If ever we realize the best of our chemical propellents, the mass ratio will be reduced to 7.5 : 1. However, the errors of our simplified formula are now too great to be ignored, and in practice we shall need a mass ratio of about 60 : 1. In a single structure this ratio is not attainable. How then have the Russians launched a satellite? The answer is, by staging the propulsion system so that as one rocket finishes its job another takes over. Once more looking at our simple formula, if M_2 comprises a second rocket and reduces its mass to M_3, we have

$$v = I_1 g \log \frac{M_1}{M_2} + I_2 g \log \frac{M_2}{M_3}$$

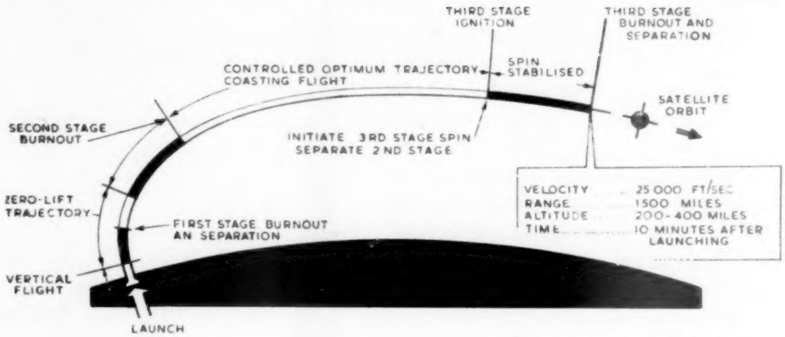


By courtesy of N.R.L., Washington, D.C.

FIGURE 9. *Vanguard launching vehicle*

Therefore, by staging our propulsion system, the limitations imposed by the propellents may be overcome. In theory we may achieve what final velocity we like, but it will be at the expense of overall mass ratio. The Vanguard[3] has three stages of propulsion and the overall mass ratio is about 1000 : 1. At launching, Vanguard weighs 22,600 lb. and its satellite weighs 21·5 lb. The initial thrust of Vanguard is 28,100 lb., so we may contemplate on the magnitude of the first stage rocket which launched Sputnik II weighing 1,100 lb. into Space.

Quite literally the Law of Diminishing Returns works with drastic effect if we depend solely on achieving high mass ratios. Greater dividends arise from using propellents of greater specific thrust, but we know the limitations of chemical propellents. From where else may we get our energy? Shepherd[4] proposes many possibilities, but he is careful to point out that some of these will be of use only if a launching platform is available in Space. However, I should



By courtesy of N.R.L., Washington, D.C.

FIGURE 10. *Diagram of ascent trajectory of Vanguard launching vehicle*

like to close this talk with mention of one of the possibles. If we use hydrogen of molecular weight 2 heated in a nuclear furnace to say 3000°K, we shall have specific thrusts in the region of 800 lb./lb./sec. Where is the rub?

Finally, I must conclude by saying I am deeply conscious that this talk has merely skimmed over the subject which the title portrays. I am aware that what has been said will have a familiar ring to rocket experts within the audience, but if anyone is now convinced that there is some art in designing rocket engines, then I must be content.

The author acknowledges the permission of the Chief Scientist, Ministry of Supply, to give this talk.

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APPENDIX

1. Consider a body of mass m, moving with velocity v. Let this body act as a rocket according to definition and in an instant of time δt, eject some fraction of itself, of mass δm, in such a manner that δm acquires a velocity u, where $v > u$. Assume that relative to the body, the velocity of ejection is constant, i.e., $(v - u)$ is constant.

Because no external force is acting, the momentum of the system is constant

$$\therefore \; mv = (m - \delta m)\,(v + \delta v) + \delta m.\, u$$

$$\therefore \; m\,\delta v = \delta m\,(v - u)$$

If $(v - u) = -\bar{V}$, the velocity of ejection relative to the body

$$\delta v = -\bar{V}\frac{\delta m}{m}$$

$$\therefore\ v_2 - v_1 = \bar{V}\log\frac{M_1}{M_2}$$

where v_1 is the velocity of the body when its mass is M_1.

v_2 is the velocity of the body when its mass is M_2.

If the body starts from rest $v_1 = 0$ and the general expression is

$$v = \bar{V}\log\frac{M_1}{M_2} \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (I)$$

2. The acceleration of the body when the velocity is v, is $\frac{dv}{dt}$ and the thrust required is $m\frac{dv}{dt}$, which equals $-\bar{V}\frac{dm}{dt}$. Therefore the thrust of the rocket is determined by the rate of ejection of mass and the velocity, relative to itself, given to the ejected mass. $-\frac{dm}{dt}$ is the measure of the rate of reduction of the mass of the rocket, or the rate of propellent consumption, and 'Specific Thrust' is defined as the thrust divided by the rate of propellent consumption.

$$\therefore\ \text{Specific Thrust} = \frac{m\frac{dv}{dt}}{-\frac{dm}{dt}} = \bar{V} \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (II)$$

In conformity with normal engineering practice, expressing thrust in pounds weight and propellent consumption in pounds mass per second, we are obliged to express

$$\text{Specific Thrust, I as } \frac{\bar{V}}{g} \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (III)$$

which has the dimensions of time.

Specific Thrust is numerically identical with the term commonly used, Specific Impulse, and is the inverse of Specific Fuel Consumption, the important index of performance in the gas turbine field.

3. Consider a reservoir which contains gas at pressure P_1, temperature T_1, and density ρ_1, and let this reservoir be connected to another reservoir maintained at pressure P_2 which is less than P_1. Let the first reservoir be sufficiently large that the gas within it has no sensible velocity and that P_1, T_1 and ρ_1 remain constant as the gas flows into the second reservoir at pressure P_2, with velocity v_2 and at temperature T_2.

Assume that the gas is perfect and the transition is isentropic.

By definition of Mach number, Mn,

$$v_2 = Mn_2 \sqrt{\gamma \quad g \frac{R}{M} \cdot T_2}$$

where γ is the ratio of specific heats of the gas

g is the acceleration due to gravity

R is the universal gas constant

M is the molecular weight of the gas.

By the Gas Laws and because of the conservation of energy

$$\frac{T_1}{T_2} = \left[1 + \left(\frac{\gamma - 1}{2} \right) \cdot (Mn_2)^2 \right]$$

$$= \left(\frac{P_1}{P_2} \right)^{\frac{\gamma - 1}{\gamma}}$$

$$\therefore \quad T_2 = T_1 \left(\frac{P_2}{P_1} \right)^{\frac{\gamma - 1}{\gamma}}$$

$$\text{and } Mn_2 = \left[\left(\frac{2}{\gamma - 1} \right) \left[\left(\frac{P_1}{P_2} \right)^{\frac{\gamma - 1}{\gamma}} - 1 \right] \right]^{\frac{1}{2}}$$

$$\therefore \quad v_2 = \left[2g \left(\frac{\gamma}{\gamma - 1} \right) \frac{R}{M} \cdot T_1 \left[1 - \left(\frac{P_2}{P_1} \right)^{\frac{\gamma - 1}{\gamma}} \right] \right]^{\frac{1}{2}} \quad \ldots \text{(IV)}$$

$\left(\frac{\gamma}{\gamma - 1} \right) \frac{R}{M}$ may be expressed as K_P

where K_P is the specific heat of the gas at constant pressure.

K_pT_1 is the Total Heat or Enthalpy of unit mass of the gas and is a measure of the realizable energy of the gas.

Transforming equation IV

$$\frac{v_2^2}{2g} = K_pT_1\left[1-\left(\frac{P_2}{P_1}\right)^{\frac{\gamma-1}{\gamma}}\right] \quad \ldots \quad \ldots \quad \ldots \quad (V)$$

Thus the pressure ratio $\frac{P_1}{P_2}$ determines what fraction of the Total Heat is converted into kinetic energy.

4. Consider the adiabatic flow of gas. By the conservation of energy

$$d\left(\frac{P}{\rho}\right) + K_v dT + v dv = 0$$

By the Gas Laws

$$d\left(\frac{P}{\rho}\right) = (K_p - K_v)\ dT$$

$$\therefore\ K_p dT + v\ dv = 0$$

$$\text{or}\quad \left(\frac{\gamma}{\gamma-1}\right) d\left(\frac{P}{\rho}\right) + v\ dv = 0$$

If the flow is isentropic

$$\frac{P}{\rho^\gamma} = \text{constant}$$

$$\text{and } d\left(\frac{P}{\rho}\right) = (\gamma-1)\ \frac{P}{\rho}\cdot\frac{d\rho}{\rho}$$

$$\therefore\ \gamma\ \frac{P}{\rho}\cdot\frac{d\rho}{\rho} + v\ dv = 0$$

But $\gamma\frac{P}{\rho} = a^2$ where a is the local velocity of sound

$$\therefore\ a^2\ \frac{d\rho}{\rho} + v\ dv = 0$$

By continuity

$\rho \, Av$ = constant where A is the cross sectional area of the flow path

$$\therefore \quad \frac{d\rho}{\rho} + \frac{dA}{A} + \frac{dv}{v} = 0$$

$$\therefore \quad v\,dv - a^2 \left[\frac{dA}{A} + \frac{dv}{v}\right] = 0$$

$$\therefore \quad \frac{dA}{A} + \frac{dv}{v}\left[1 - \frac{v^2}{a^2}\right] = 0$$

Therefore, when the flow is subsonic, $v < a$ and dA is negative if dv is positive. When the flow is supersonic, $v > a$ and dA is positive if dv is positive.

When $v = a$
$dA = 0$

Therefore, if gas flows from a subsonic régime to a supersonic régime, it must be accelerated in a converging passage to sonic velocity and then accelerated to supersonic velocity in a diverging passage. At the throat of the passage where the cross sectional area is a minimum, the velocity is sonic.

When a gas flows from a stagnant region through a convergent-divergent nozzle, a minimum pressure ratio is required across the nozzle in order to establish a supersonic régime. From the foregoing it may be shown that the pressure ratio $\frac{P_1}{P_2}$ must exceed the value $\left(\frac{\gamma + 1}{2}\right)^{\frac{\gamma}{\gamma - 1}}$

5. A convergent-divergent passage (Laval nozzle) is necessary to accelerate the gas to supersonic velocity. If the area of the throat of the nozzle is A_t, and A_2 is the cross-sectional area of the nozzle at the exit plane where the pressure is P_2, then from reasons of continuity, the ratio $\frac{A_2}{A_t}$ is uniquely determined by the ratio $\frac{P_1}{P_2}$. Therefore for a given value of A_t, A_2 must vary as $\frac{P_1}{P_2}$ varies. Conversely if A_2 is fixed, P_2 is determined uniquely by P_1 and P_2 may then differ from the ambient pressure P_0. If A_2 is varied so that P_2 remains equal to P_0, then assuming constant Total Heat, the variation of Specific Thrust with respect to pressure ratio is tabulated below. The detum pressure ratio is taken as 20 : 1 and the Specific Thrusts are given as percentages of the value at this ratio. The value γ is taken as 1·25. It should be noted that $\bar{V}$ of equations I, II and III is the same as v_2 of equations IV and V.

$\dfrac{P_1}{P_2}$	$\sqrt{1 - \left(\dfrac{P_2}{P_1}\right)^{\frac{\gamma - 1}{\gamma}}}$	*Specific Thrust as Percentage of Value* when $\dfrac{P_1}{P_2} = 20$
1	0	0
10	0·601	89·5
20	0·6714	100
30	0·7025	104·6
40	0·7223	107·4
50	0·7367	109·8
60	0·7478	111·3
70	0·7566	112·6
80	0·7639	113·7
∞	1·000	149·0

See Figure 3 on page 482.

When P_2 is greater than the ambient pressure P_0, the gases are not fully expanded at the exit plane of the nozzle and in addition to the momentum thrust there is a pressure thrust equal to $(P_2 - P_0)\ A_2$.

The total thrust is now

$$\rho_2 A_2 \ . \ \frac{v_2^2}{g} + (P_2 - P_0)\ A_2$$

The effective specific thrust I_0 is

$$\frac{v_2}{g}\left[1 + \frac{P_2 g}{\rho_2 v_2^2}\left(1 - \frac{P_0}{P_2}\right)\right]$$

If I_D is the designed specific thrust (when $P_0 = P_2$)

$$I_D = \frac{v_2}{g}$$

$$I_0 = I_D\left[1 + \frac{P_2 g}{\rho_2 v_2^2}\left(1 - \frac{P_0}{P_2}\right)\right]$$

$$= I_D \left[1 + \left(\frac{\gamma - 1}{2\gamma}\right) \frac{\left[1 - \dfrac{P_0}{P_2}\right]}{\left[\left(\dfrac{P_1}{P_2}\right)^{\frac{\gamma - 1}{\gamma}} - 1\right]} \right]$$

and

$$\frac{\Delta I}{I_D} = \frac{I_0 - I}{I_D} = \left(\frac{\gamma - 1}{2\gamma}\right) \frac{\left[1 - \dfrac{P_0}{P_2}\right]}{\left[\left(\dfrac{P_1}{P_2}\right)^{\frac{\gamma - 1}{\gamma}} - 1\right]} \qquad \ldots \text{(VI)}$$

Using this expression and taking $\gamma = 1 \cdot 25$, the tabulation below shows the percentage increases in specific thrust as the operating altitude increases from Sea Level to Infinity for rockets of design pressure ratio, 20, 40, 60 and 80, having nozzles giving full expansion at Sea Level.

Altitude Feet $\times 10^{-3}$	$\frac{\Delta I}{I_D}$ %				
	$\frac{P_1}{P_2}$	20	40	60	80
0	—	0	0	0	0
20	—	6·57	4·95	4·27	3·85
40	—	9·93	7·48	6·44	5·82
60	—	11·30	8·51	7·33	6·63
80	—	11·84	8·92	7·67	6·94
100	—	12·07	9·07	7·82	7·07
∞	—	12·18	9·17	7·89	7·13

See Figure 4 on page 484.

6. Equation I may be expressed as

$$v = Ig \log \frac{M_P + M_B}{M_B}$$

where M_P is the weight of propellent consumed,

M_B is the weight of the missile at 'all burnt'.

For constant weight of propellent consumed the relative importance of specific thrust and weight at 'all burnt' is given by

$$\frac{d\,M_B}{M_B} = \left(\frac{M_P + M_B}{M_P}\right) \log \left(\frac{M_P + M_B}{M_B}\right) \cdot \frac{dI}{I}$$

and the percentage change in 'dry' weight equivalent to 1% change in specific thrust is

$$\left(\frac{M_P + M_B}{M_P}\right) \log \left(\frac{M_P + M_B}{M_B}\right)$$

If $M_B = M_E + M_S$
where M_E = engine weight,
M_S = structure weight + payload
and if M_S is constant

$$dM_B = dM_E$$

and
$$\frac{dM_B}{M_B} = \frac{M_E}{M_B} \cdot \frac{dM_E}{M_E}$$

for a small change in weight

$$\therefore \quad \frac{dM_E}{M_E} = \frac{(M_P + M_B)\,M_B}{M_P \,.\, M_E} \log \left(\frac{M_P + M_B}{M_B}\right) \cdot \frac{dI}{I} \quad \ldots \text{(VII)}$$

and the percentage change in engine weight equivalent to 1% change in specific thrust is

$$\frac{(M_P + M_B)\,M_B}{M_P \,.\, M_E} \log \left(\frac{M_P + M_B}{M_B}\right)$$

For the German V.2 missile,

M_P = 19,620 lb.
M_B = 8,880 lb.
M_E = 2,050 lb.

and 1% change in specific thrust is equivalent to 8·1% change in engine weight.

In terms of M_1 and M_2 used earlier, equation VII becomes

$$\frac{dM_E}{M_E} = \frac{M_1 \cdot M_2}{M_P \cdot M_E} \log \frac{M_1}{M_2} \cdot \frac{dI}{I} \quad \ldots \quad \ldots \quad \ldots \text{(VIII)}$$

7. To consider the burning of a solid propellent charge. Let the rate of burning of the propellent surface be 'S', where

$$S \propto P^n$$

and P is the pressure at which burning takes place. If the charge be so designed that the surface area of burning remains constant, the rate of evolution of gas is proportional to 'S'. If the rate of evolution is m_1

$m_1 = k_1 P^n$ where k_1 is a constant.

If the products of combustion and their temperature are sensibly constant with small changes in pressure, the rate of mass flow of gases through the propelling nozzle is proportional to P, assuming that sonic velocity is maintained at the throat of the nozzle. If this rate of mass flow is m_2

$$m_2 = k_2 P \text{ where } k_2 \text{ is a constant.}$$

If conditions are steady

$$m_1 = m_2$$

but for equilibrium to be maintained

$$\frac{dm_1}{dP} < \frac{dm_2}{dP}$$

$$\therefore \quad k_1 n P^{n-1} < k_2$$

$$\therefore \quad n < \frac{k_2}{k_1} \cdot \frac{1}{P^{n-1}}$$

$$\text{i.e.,} \quad n < \frac{m_1}{m_2}$$

$$\therefore \quad n < 1$$

In practice, values of n greater than 0·8 are never used, thereby making some allowance for variations in surface area and variations in combustion products.

8. To consider the design of solid propellent charges to provide burning surfaces of constant area.

The simplest possible shape of charge is a solid cylinder of which only the flat ends are exposed to combustion. Such a charge, with only one end exposed is called 'cigarette burning'. Applications exist for this type, but it is not always suitable. A more common and useful type of charge is cylindrical with an axial conduit, and the burning surface is that exposed within the conduit. Burning proceeds radially outwards, the surface area of burning being the product of the length of the charge and the perimeter of the conduit. As the length of the charge is normally constant, constant surface area of burning demands that the perimeter of the conduit be held constant.

Consider a cylindrical charge with a co-axial conduit of circular form. The perimeter of the conduit, of diameter d, is πd. As burning proceeds, d increases; therefore the surface area of burning increases.

Now consider a cylindrical charge of diameter d_1, having a co-axial conduit of diameter d_2, and let burning occur on the outside curved surface and on the surface of the conduit. If both surfaces have the same rate of burning, b, after a time t, the outer and inner diameters are respectively $(d_1 - 2bt)$ and $(d_2 + 2bt)$. The total surface area of burning is $\pi l\,[d_1 - 2bt + d_2 + 2bt]$, where l is the length of the cylinder.

Therefore the surface area of burning is

$$\pi l\,(d_1 + d_2) \text{ which is constant.}$$

Now consider a corrugated surface, of which the convolutions are formed by alternate convex and concave semi-circular arcs. The radii of the convex and concave arcs need not be identical. If this corrugated surface is the burning surface of a propellent, it will maintain constant superficial area.

If the corrugated sheet is regarded as the developed surface of a conduit, the perimeter of the conduit will appear as the familiar star-centred charges, maintaining constant area of burning.

9. To consider central orbits under Newtonian attraction.

Consider a body of mass m, moving freely in an orbit and subject only to the gravitational attraction of mass M. Let r be the distance between m and M, and θ the angle between a fixed polar co-ordinate and the instantaneous co-ordinate of m.

The kinetic energy of the body $= \frac{1}{2}\, m\, v^2 = \frac{1}{2}\, m\,(r^2\,\dot{\theta}^2 + \dot{r}^2)$

The potential energy of the body, gained in moving from distance R_0 to a greater distance r, is

$$mg_0R_0^2 \int_{R_0}^{r} \frac{dr}{r^2} = mg_0R_0^2 \left[\frac{1}{R_0} - \frac{1}{r}\right]$$

where g_0 is the gravitational acceleration at distance R_0.

By conservation of energy,

$$\frac{1}{2}\, m\,(r^2\,\dot{\theta}^2 + \dot{r}^2) + mg_0R_0^2 \left[\frac{1}{R_0} - \frac{1}{r}\right] = \text{constant} = C$$

Since there is no force normal to the radius vector,

$$2\dot{r}\,\dot{\theta} + r\,\ddot{\theta} = \frac{1}{r}\,\frac{d\,(r^2\dot{\theta})}{dt} = 0$$

Hence $r^2\,\dot{\theta} = \text{constant} = k.$

$$\text{Let } u = \frac{1}{r} \text{ so that } \dot{r} = \frac{-1}{u^2}\cdot\dot{u}$$

$$\text{and } \dot{\theta} = ku^2$$

$$\therefore\quad \frac{1}{2}\,k^2u^2 + \frac{1}{2}\,.\,\frac{\dot{u}^2}{u^4} - g_0R_0^2u = \frac{C}{m} - g_0R_0$$

$$\dot{u} = \frac{du}{d\theta}\,\dot{\theta} = ku^2\cdot\frac{du}{d\theta}$$

$$\therefore\quad \frac{1}{2}\,k^2u^2 + \frac{1}{2}\,k^2\left(\frac{du}{d\theta}\right)^2 - g_0R_0^2u = \frac{C}{m} - g_0R_0$$

$$\text{i.e., } \left(\frac{du}{d\theta}\right)^2 = \frac{2}{k^2}\left[\frac{C}{m} - g_0R_0\right] + g_0^2\,\frac{R_0^4}{k^4} - \left(u - g_0\,\frac{R_0^2}{k^2}\right)^2$$

Let $a^2 = \frac{2}{k^2} \left(\frac{C}{m} - g_0 R_0\right) + g_0^2 \frac{R_0^4}{k^4}$

$b = g_0 \frac{R_0^2}{k^2}$

Then $\frac{1}{r} = b + a \sin \theta$

which is a circle if $a = 0$
an ellipse if $a < b$
a parabola if $a = b$

If $a = 0$

$$2\frac{C}{m} - 2g_0R_0 + g_0^2 \frac{R_0^4}{k^2} = 0$$

$$\therefore \quad v^2 + 2g_0R_0^2 \left[\frac{1}{R_0} - \frac{1}{r}\right] - 2g_0R_0 + g_0^2 \frac{R_0^4}{r^2v^2} = 0$$

since $\dot{r} = 0$

$$\therefore \quad v^4 - 2g_0 \frac{R_0^2}{r} \cdot v^2 + g_0^2 \frac{R_0^4}{r^2} = 0$$

$$\therefore \quad v^2 - g_0 \frac{R_0^2}{r} = 0$$

and the circular orbital velocity is $R_0 \sqrt{\frac{g_0}{R_0 + h}}$
where h is the height above the Earth of radius R_0.
If $a = b$, the orbit is a parabola, going to infinity

$$\frac{2}{k^2} \left[\frac{C}{m} - g_0R_0\right] + g_0^2 \frac{R_0^4}{k^4} = g_0^2 \frac{R_0^4}{k^4}$$

$$\therefore \quad \frac{C}{m} = g_0R_0$$

$$\therefore \quad \frac{1}{2} v^2 + g_0R_0^2 \left[\frac{1}{R_0} - \frac{1}{r}\right] = g_0R_0$$

$$\therefore \quad v^2 = 2g_0 \frac{R_0^2}{r}$$

$\therefore$ The minimum escape velocity from a circular orbit at height h above the earth, of radius R_0 is

$$\mathbf{v} = R_0 \sqrt{\frac{2g_0}{R_0 + h}}$$

DISCUSSION

THE CHAIRMAN: How refreshing it has been to hear so clear and informative a talk, delivered with authority! I have heard one or two rocket talks during the past few years in which the speakers have gone into great detail as to how to reach Pluto, but have not worried in the least about details of rocket propulsion! To-day Mr. Dunning has put us very much in the picture.

MR. S. C. NORRINGTON: I should like to ask why the common factor spin is not used in these rockets? When you are firing a bullet you always expect it to have a spin from your rifle.

THE LECTURER: Yes, if we want a bullet to go in a straight line; but we do not always want a rocket to go in a straight line.

MR. NORRINGTON: You want to get the rocket (or rockets) transporting the satellite outside the world's atmosphere, presumably?

THE LECTURER: If you are talking about satellites, then perhaps Mr. Moore can answer better than I. The only reason that I can think of for giving spin to a satellite moving out of space is in order to create an artificial gravity in the thing itself. Once we have a satellite moving in an orbit round the Earth, spin makes no controlling contribution to the locus of the orbit.

MR. NORRINGTON: Do you want to get the satellite outside the force of gravity?

THE LECTURER: Spinning it would not help to that end. A satellite normally moves in an elliptical orbit. It is subject to the Earth's gravitational field, and for this reason possesses potential energy. The sum of its potential energy and its kinetic energy remain constant. If we assume that the perfect orbit is a circle around the Earth, then both the potential energy and the kinetic energy of the satellite each remain constant. If the satellite by some means is given an increase in velocity, that is an increase in kinetic energy, it will begin to move away from the Earth, thereby increasing its potential energy and losing kinetic energy, and the orbit will become an ellipse. However, if it is given a sufficiently large increase of velocity its orbit will become a parabola and the satellite will continue to move away from the Earth. The velocity necessary to give a parabolic orbit is the minimum escape velocity. [See also Additional Note by the Lecturer on page 510.]

MR. J. M. AUCKEN: I should like to ask the lecturer two questions: firstly, the feasibility of using some kind of fuel which will give a low acceleration for a long time, as against a high acceleration for a short time. Secondly, could the lecturer say something about fuels of the boron hydride type?

THE LECTURER: I cannot say anything about boron fuels, for obvious reasons, but I can try to answer the question about fuels giving a low acceleration for a long time. We must not get confused. We use the propellents to develop a certain thrust, and the acceleration given to the body is a function of that thrust and is not necessarily linked with the characteristics of the propellent. Because propellent is being consumed the weight of the missile is being reduced, and if the thrust is maintained constant the acceleration of the missile is increased. As we know, the acceleration imparted to a body is a function of the thrust being developed and the mass of the body. In my printed paper I examine this inter-relationship between the thrust and the mass of the rocket more thoroughly than I was able to do in my talk. For a given quantity of propellent we have a certain amount of stored up energy which is utilized in a given period of time. The integral of the thrust with respect to time we call the

total impulse, which is determined by the quantity of propellent we use. We must not confuse the characteristics of the propellent and the specific thrust of the propellent with the acceleration we give to the body.

MR. AUCKEN: The reason I ask this question is from the point of view of projecting a human into space, because the 'G' tolerance of the human is comparatively low, and I wondered if there was any convenient method of keeping acceleration low and still being able to carry enough fuel to use that acceleration over a long period of time?

THE LECTURER: There are ways of keeping the acceleration below a certain maximum; there is also the structure to consider. The greater acceleration you impose on the structure, the greater is the loading.

AIR VICE-MARSHAL D. W. R. RYLEY, C.B., C.B.E. (Director of Engineering (Guided Weapons), Air Ministry): The lecturer in his talk seemed to indicate that in order to burn fuel for a rocket engine in a ballistic missile it was essential to use a liquid. As one who is responsible for servicing rocket engines (and having had a vivid description and demonstration given to me of what would happen if we made mistakes), I am rather perturbed at this and I feel that perhaps Mr. Dunning has underrated the requirements or the possibilities of solid propellents—especially in view of the fact that I understand success has been achieved in America on a rocket called 'Polaris'.

THE LECTURER: I think I gave a clue on the possible advantages of solid propellent units. Once we have overcome the development snags we can guarantee their performance, unless by some mischance they have been subject to mishandling. There is a lot to be said in their favour, and I do sympathize with all the Service people who prefer solid propellents to liquid propellents. Generalizing, I said we would use solid propellents for periods up to 30 seconds, and liquid propellents for periods of a minute or more, but I did point out that this differentiation was subject to many qualifications and that if I embarked on discussing these I could devote a whole lecture to them.

THE CHAIRMAN: We have heard a great deal about these new fuels without going into any specific cases. During the last fifteen years fuels have developed out of all recognition. Assuming that we do not develop any kind of nuclear fuel in the near future—in other words, assuming that we still have to fall back upon the development of the chemical fuels that we now possess—does Mr. Dunning consider that the development of those would be adequate for some form of interplanetary travel?

THE LECTURER: One of the references I quote is from a paper 'Is there an Energy Limit?', which deals with chemical propellents. The lower the limit of energy we can realize, the more arduous is the task of the engineer, but I believe it is feasible to achieve some form of interplanetary travel using our known chemical propellents.

MR. R. F. STEWART: Could I ask the lecturer what the combustion chamber of the rocket is made of so as to withstand this enormous heat?

THE LECTURER: Well, I said that the combustion temperature was about 3,000 degrees kelvin, but I must be careful to point out that we take every step to ensure that the inner wall of the combustion chamber does not reach that temperature. We can use steel and nickel, but of course we pass one of the propellents through the jackets round the wall of the combustion chamber to keep it cool, and use such dodges as varying the mixture strength of the propellents near the walls of the chamber. This is degrading the performance of the rocket, but it is an artifice to which we resort.

MR. S. L. BRAGG (Rolls-Royce Ltd., Derby): I should like Mr. Dunning to amplify a little his comments on his graph of minimum specific weight. We were told in the lecture that weight was relatively unimportant compared with specific thrust or engine performance, and so, if one assumes that a large engine is more likely to be efficient than a small engine, the optimum engine has a good deal bigger thrust than the minimum specific weight engine shown on Mr. Dunning's graph.

A second point, often advanced when arguing this question of what is the right size of engine to make, is that of reliability. If you have, as seems to be the present case, only a ninety per cent chance of a success in any given firing, then the more engines you have the more likely you are to have one of them not working. Against this you must balance the fact that if you have only a given amount of money to spend on development, the smaller the engine the more likely you are to make it reliable. It seems to me that there are some factors here which the lecturer did not mention, and I wonder whether he could now do so.

THE LECTURER: I think Mr. Bragg has actually given the clue to the answer to his question, but he has made an assumption which I cannot accept—that the bigger the engine, the more efficient it is. I cannot accept that argument at all. On this question of using multiple units to achieve a given thrust instead of one big unit, it is my contention that the reliability of an aero-engine or any other propulsion device is not primarily a function of the number of its components, but of the development that has been put into it. If, say, we put 500 hours of work into developing a small unit because we had the facilities to do so, but are unable to put in, say, more than 10 hours on something much bigger because we have not the proper facilities, then the small unit is more reliable than the larger. I have argued with Mr. Bragg about this on previous occasions and I have no doubt we shall continue in the future. My point is that overall reliability is more dependent on the development effort than on the number of components, and I do not accept that as you increase size you necessarily increase efficiency.

MR. BRAGG: If that is the case you want to work on the other side—on the smaller engine!

THE LECTURER: I am not saying that the smaller engine is more efficient; I am saying that we need not necessarily lose by using a smaller engine. When discussing the Square Cube Law I deduced that in practice we can achieve the optimum engine from a weight point of view, but I also said that the rocket designer must not go on striving for high specific thrust, if by so doing he incurs a weight penalty which results in an overall loss of performance. However, it may pay on occasions to add some weight and thereby achieve an overall gain. Is it not the indication of a good designer that he makes the best compromise?

MR. DENNIS S. CARTON (College of Aeronautics): I should like to thank Mr. Dunning for a most interesting lecture. There is, nevertheless, one small point upon which I should like to comment. At times he seemed to use the terms 'mass' and 'weight' as though they were synonymous. For instance, in one of the graphs M_1 was defined as the mass of a vehicle when full, and M_2 as the empty mass—in the course of the lecture their difference was said to be the total weight of propellents.

Whilst this is an accepted usage in describing states at the Earth's surface, no one would accept the free fall state of 'weightlessness' being described as 'masslessness'.

THE LECTURER: I thought I had been careful and I did not know I had dropped a clanger on any of the graphs! When I was speaking about specific thrust I was very careful to get it into working units. I talked about thrust in pound weight and propellent ejection in pounds mass per second. After all, we are dealing with masses and weights in this topic, and I do not know whether I should have actually used the

term weight when I was meaning mass or not. But certainly you cannot get rid of mass.

MR. CARTON: In my experience many people find that mixing the terms 'mass' and 'weight' can cause confusion in this context. Provided that a group have an agreed, clear set of definitions, they do not get mixed up. It is in communication to those outside the group that confusion may arise.

THE LECTURER: I agree. I agree that we should be clear as to whether we mean weight or whether we mean mass. If we have got a pound mass on this earth it is still a pound mass on the moon but it does not weigh a pound.

THE CHAIRMAN: I am sure that there are many more questions that people would like to ask, but we have already kept Mr. Dunning here for a long time. We are extremely grateful to him for coming here to-day; we all know how busy he is. He has done a great deal this afternoon to clarify our ideas about rocketry and rocket propulsion, and in an age like the present one it is most important that our ideas should be clear.

A vote of thanks to the Lecturer was carried with acclamation and, another having been accorded to the Chairman, the meeting then ended.

ADDITIONAL NOTE

Mr. Dunning writes:

In answering Mr. Norrington at the conclusion of my lecture [see page 507 above] I may have given the impression that spin never serves any useful purpose, and this would be misleading. There is no purpose in imparting spin to a guided missile because this would nullify the normal methods of control, but there are some rocket applications in which spin can be useful. The film of the Skylark test vehicle may itself provide an example. This vehicle is not subject to any aerodynamic control, and we rely on its inherent stability to maintain a pre-selected launching trajectory. Spin would be beneficial here because it would add to the directional stability. I should also have mentioned that the third stage of Vanguard is given spin to give it directional stability when being placed into its orbit. However, I must repeat that spin is contrary to the requirements of a *guided* missile and also is not a controlling factor when considering the motion of a satellite once it is in its orbit.

WORLD HUNGER AS A BIOCHEMICAL PROBLEM

The E. Frankland Armstrong Memorial Lecture by

N. W. PIRIE, F.R.S.,

Head of the Biochemistry Department, Rothamsted Experimental Station, *delivered to the Society on Wednesday, 12th March, 1958, with Sir Selwyn Selwyn-Clarke, K.B.E., C.M.G., M.C., M.D., F.R.C.P., Chairman, Commonwealth Section, in the Chair*

THE CHAIRMAN: I first have to make an apology to you on behalf of Sir John Russell, who is unfortunately snowed up in Oxfordshire. He is particularly sorry to be absent, because he was the Director of the Rothamsted Experimental Station for something like 31 years and at the end of that period he had with him as a colleague our speaker to-day, Mr. Pirie.

This lecture commemorates the memory of a scientist who came from a family of scientists. Dr. Armstrong was elected a Fellow of the Royal Society for his outstanding research work, particularly on the application of organic chemistry to industrial uses. He was also President of this Society from 1942 to his death in 1945. We are delighted to have with us this afternoon Dr. Armstrong's widow, his daughter and son, and sister.

The son of a famous painter, Sir George Pirie, Mr. Pirie had a brilliant academic career at Emmanuel College, Cambridge. After working in the Biochemistry laboratory for some time, he joined the staff of the Rothamsted Experimental Research Station, working first as virus physiologist and then as Head of the Biochemistry Department. He is more than well qualified to speak to us on his chosen subject. There is little dispute about its importance. Some three weeks ago Bishop Fulton Sheen gave a broadcast in which he referred to the large numbers of people in the world who have too little to eat, and the many who were actually starving. I myself have seen tens of thousands of people starved to death, reduced to eating grass and bark, even throwing their children into the flooded river in order not to see them die of starvation.

The following lecture, which was illustrated with lantern slides, was then delivered:

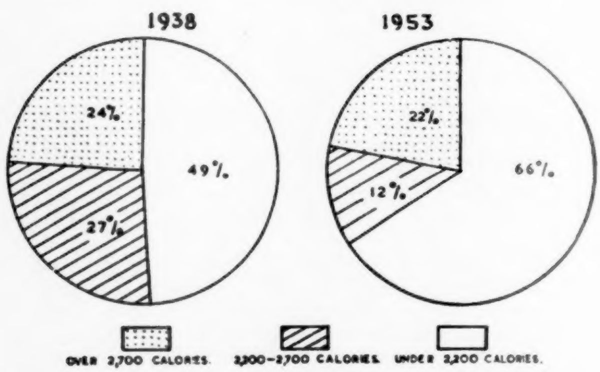
THE LECTURE

Many factors are involved in any attempt to solve a practical problem by means of research. We must be sure that the problem exists and that its nature has been defined. There must be unused academic knowledge or a research plan for getting the knowledge that is needed. There must be reason to think that the necessary scientists exist or could be trained. Finally, and this is the stage at which most difficulty is generally experienced, there must be reason to think that the research-controlling bodies will allow the work to go on, finance it, and co-operate in getting it used if it is successful.

There will be a little argument about the reality of a world food shortage.

Hitherto some parts of the world have been short of food all the time and all parts some of the time; it is only during the last century that a significant proportion of the population in the more favoured nations has avoided the common lot of mankind and has been able, year after year, to assume that it would always have enough to eat. With unsold surpluses in a few countries there is a risk that the world shortage may not get the attention it deserves. Fortunately the international organizations, such as the Food and Agricultural Organization, the World Health Organization and the United Nations Children's Fund, recognize the problem. The need for more food has been clearly stated in many of their publications, and they have laid especial emphasis on the fact that the disparity in nutritional status between the better and the worse fed countries is increasing as the years go by and not diminishing as is commonly assumed. Gunnar Myrdal (1957) has analysed the reasons for this extremely lucidly in his book, *Economic Theory and Under-Developed Regions.*[1]

FIFTEEN YEARS INCREASE IN WORLD HUNGER



Distribution of world population according to average daily supply of calories

THE CONVENTIONAL APPROACHES

Before discussing the contemporary rôle of biochemistry in combating this state of affairs we may consider the conventional approaches. Food shortages have generally been ameliorated by bringing new lands into cultivation. It was primarily the extension of the area farmed that made Malthus wrong, or at any rate premature. The process could still go a little further and open up parts of South America, Africa and West China. But no regions remain that are at all comparable in area to those brought under cultivation for the first time during the nineteenth century. The alternative to increasing the area farmed is to get more off each acre. Better varieties of existing crops should be selected or created. This would continue a process that is as old as agriculture but, although valuable improvements will undoubtedly be made, it is unlikely that our improvements will be as striking as those wrought by primitive man when he replaced emmer

by wheat or teosinte by maize. We may still be a long way from the theoretical limit to photosynthetic efficiency, but the more efficient market gardens are probably not far from the practical limit to it.

Whatever the variety used, its yield is controlled by light, temperature, water and fertilizers. We can do little about the first except for supplying special crops with a little extra light in the dark months. The continuous illumination of large areas at an intensity that would be useful in photosynthesis can hardly be contemplated. So, too, with temperature. Much could be done to warm the soil and air by using the waste heat from power stations, but, even in heavily industrialized regions, the total area that could be so treated remains small. The study of micro-climates, the intelligent siting of windbreaks, and the use of fans and smudge fires could do much to mitigate the effects of unseasonable weather. These things also could only be done over small areas. The only really promising method of increasing the temperature of large areas of farm land is to hasten the spring thaw in snow-covered regions by scattering some dark coloured material on the snow so as to diminish the amount of energy wasted when sunlight is reflected back into space.

The other two factors that affect crop yields are more fully controllable. Irrigation is an ancient art, and the area irrigated is being steadily extended. This would be good in any event; it has the added merit that many of the areas that remain to be irrigated are in regions where there is an acute food shortage. But the amount of irrigating that can be done depends on the amount of water that is available and this is by no means unlimited. At present less than 5 per cent of the world's food supply depends on the control of water on an engineering scale. Nevertheless, so much of the world's water is already under control that it would be unrealistic to look forward to any further immense extension by normal techniques. Much could be gained if water, at present used for cotton and other inedible crops, were diverted to food, but this will not provide for the doubling or trebling of the food supply that will probably be necessary soon. The position will, of course, be radically altered if rainfall could be redistributed or if power became so abundant that very large amounts of de-salted sea water could be pumped into deserts. Nuclear energy may make this possible, but it would be most unwise to assume that it is certain to be possible. Nuclear energy brings with it a completely new set of problems and hazards. Some have been recognized but not solved; the disposal of large amounts of radio-active waste, for example. Others will only be recognized as the power stations come into operation. These problems may prove as intractable as hunger itself. Although it is vital that the irrigated area should be extended, this extension will not alone be great enough to solve the world's food problems.

Fertilizers could have a much bigger effect on productivity. The main food growing areas in the temperate zone get very little and some areas get none at all. If the problem were simply to increase the amount of food in the world, without regard to the distribution of that food, then the use of more fertilizer in the U.S.A. and the U.S.S.R. would probably meet all needs for at least a generation, and these countries would be well able to make the extra fertilizer. But food must

be where the mouths are. Both economically and practically, the idea of shipping from one country to another the main foodstuffs for populations larger than that of Britain is intimidating. Without going so far as to suggest that, as in King Solomon's day, international trade should only be in such things as

'gold and silver, ivory and apes, and peacocks',

it would seem prudent for a country not to expose its essential foodstuffs to the vicissitudes of world trade. Fertilizers will only have their full beneficial effect when they become more amply available in South and East Asia, where food shortage is most acute. These fertilizers will not be entirely synthetic, but there is not space to enlarge here on the part that biochemistry will play in devising methods of sewage disposal that satisfy the conflicting claims of economy, hygiene and aesthetics.

These conventional modes of approach to the problem of world feeding are of great importance, and it is possible that they can, on their own, supply a full solution to the problem. It is with no intention of belittlement that they have been treated briefly here, but research along these lines is already so much more ample than research on complementary lines that further discussion is unnecessary. This much is already part of the policy of many governments and of the international organizations.

Other directions of approach have this in common: they depend on the idea that, as well as trying to grow more, we should try to make better use of what we grow already. Again, some aspects of this approach are getting attention now. It is so obvious that effort and land are wasted when a crop is grown only to be ruined by a pest or disease, that the need for research on immune or tolerant strains and on methods of preventing the spread of pests and diseases, is recognized. Rough estimates of the extent of these losses can be made, and when this is done there is reason to doubt whether research is going on on an adequate scale. Ordish (1952)[2] estimates that in the U.S.A. the loss is 16 G£ a year and in Britain 78 M £. In the U.S.A. much of this loss falls, admittedly, on crops like cotton and tobacco; in Britain the loss is predominantly on food crops. It is only the research that has already been done that keeps these losses from being very much greater. Bearing this in mind, and considering the scale of the potential saving, current expenditure on research designed to protect crops is foolishly niggard.

The control of pests and diseases will call for extensive biochemical research, but this is not the type of research with which this article is concerned.

THE CIRCUMVENTION OF WASTE

So much for the conventional directions of approach to the problem. The possibilities are summarized in Table I, and in it two more possibilities appear: the avoidance of losses during conversion and the recovery of useful products from wastes.

These are primarily biochemical modes and little effort has been devoted to them so far. There are many reasons for this; prominent among them is the

TABLE I. THE COMPLEMENTARY MODES OF GETTING MORE FOOD

Produce more by:	*Use better what is produced by:*
Extending the acreage	Controlling diseases
Using better plants	Avoiding destruction by pests
Controlling light	Avoiding losses on conversion
heat	Making use of wastes
water	
nutrients	

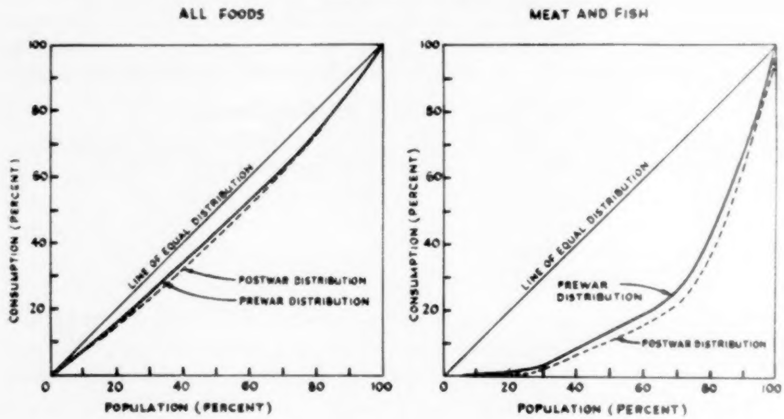
unfamiliarity of the material that would be made. Success with one of the conventional methods of approach gives us increased supplies of a familiar food or of something very similar to it, whereas the products of biochemical research, although they may be excellent by academic criteria, lack immediate appeal. This creates something of an impasse in getting the necessary research endowed. It can be argued that there is no demand for the materials that would be made; but it is hard to see how a demand could arise for things that have not yet been made. Fortunately there is a way out of the apparent impasse, because biochemistry could produce many different materials and food technology could give them many different forms. It is safe to assume that some will have both value and appeal.

It is obvious that all the components of a balanced diet are useful and it is, broadly speaking, ridiculous to say that some components are more important than others. Some, however, are more difficult to get in abundance than others and that is the justification for paying more attention here to protein than to any other foodstuff. *Mutatis mutandis*, what could be done for protein could be done for the other components of a diet.

There is some protein in almost all the parts of a plant that are eaten by men or animals; sugar cane juice and cassava tubers are exceptional in containing very little. But the concentration of protein in many foods is too low to satisfy human needs. Thus the cereal grains contain 8–15 per cent and potatoes 4–8 per cent. Any diet in which these are the main energy sources should be supplemented with a food containing a higher proportion of protein. In many parts of the world the legume seeds, which contain 25–45 per cent of protein, play an important part, but in most regions of the world, fish, meat and other animal products are preferred. There are disadvantages in following this preference. Thus, we in Britain have to import more than half our food although the calorie value (or starch equivalent) of what we grow in a year is considerably greater than that of the food we eat in a year. The gap is a consequence of animal conversion.

The rôle of animals as a source of protein concentrates is anomalous although it is generally accepted and welcomed. The animal obviously produces nothing new and gives back foodstuffs that are equivalent to only part of the vegetation that it eats. This is wasteful. The compensating merit of the animal converter

THE PATTERN OF DISTRIBUTION OF THE WORLDS FOOD



is that it wastes carbohydrate even more than it wastes protein so that, although we get back only a tenth or a twentieth of what we put into it, what we get back is a more concentrated source of protein than the animal's fodder. Conversion in an animal has some other advantages. Ruminants can thrive on easily grown vegetable material that is too fibrous to be useful as human food. The distribution of amino-acids in many animal proteins is nearer to what we think people need than it is in most vegetable proteins. This is especially true with proteins such as those in milk and eggs which have become adapted in the long course of evolution for nourishing the calf and embryo chick. It is reasonable to assume that they are well suited to the baby also. Not all animal products are adapted in this way; tripe and fish roes, for example, have a bizarre amino-acid distribution. And the needs of an adult may be very different from those of an infant. But the myth of the 'first-class protein', perfectly adapted to several dissimilar ends, dies hard and dogmatism does duty for knowledge in most domains of trophology! The final, and most important, reason for using animal products is that they have a strong gustatory appeal to most people. They are a pleasant luxury that most of the world can afford little of now and that we may not be able to afford so much of in the future. Much as we may regret it, it seems likely that animal products will, in the future, have the rôle of condiments rather than foods.

It is sometimes argued that conversion in an animal is not really inefficient because all the elements consumed by the animal, but not turned into the product we use, are passed back on to the land to go round the cycle again. No one has ever contended that an animal was a transmuter of elements; it is obvious that they pass the elements back, and this is just what is wasteful. The position is analogous to having nine men in a boat, five fishing and four throwing most of the catch overboard again. This is not totally wasted because the fish can be caught all over again; but it might be difficult to convince the five fishermen that their four colleagues were not being wasteful. So, too, with an animal. Once the

plant has converted soil components into protein it is wasteful to have an animal throwing most of what it eats back into the soil to be used again.

The losses entailed in conversion can be circumvented in two obvious ways. The first is to replace conversion by separation whenever possible; the other is to use more efficient vehicles for the conversion. Separation, that is to say the use of mechanical or chemical methods for fractionating a crop plant into its various useful components, is the basic principle of many ancient processes. Thus oil is pressed from olives and sugar from sugar cane, starch is washed away from wheat gluten in making *mien chin*, and the toxic substances are washed away from the starch before the primitive bitter manioc varieties are eaten. In a sense these are only extensions of the still more ancient processes of peeling and skinning. What is involved is the separation of a mixed starting material into components of different value. Technologists are already fully aware of the possibilities of getting oils from many other sources by similar methods. The possibilities of extending the range of carbohydrate sources are less fully exploited, and those of extracting protein are hardly exploited at all. This is odd, because protein shortage is the paramount problem of world feeding.

TABLE II

Pulped green leaves are separated into:

Juice, which gives, after coagulation	coagulum containing	proteins fats starch	food for man and other non-ruminants
	fluid containing	amino-acids amides sugars salts, etc.	medium for the growth of micro-organisms
Fibrous residue containing	most of the	cellulose hemicelluloses lignins pectin	still a fodder for ruminants and a substrate for microbial fermentation
	some of the	proteins fats starch	

The primary source of most of the protein circulating on land is the green leaf. Our normal protein foods come from this by translocation to seeds and tubers or by conversion to animal products. The leaf is therefore an obvious starting material from which to try to separate protein, and the idea has been under consideration since 1773. We now have at Rothamsted a unit able to handle a ton or more of fresh leaves in an hour and separate about half the protein from them. The process has been described elsewhere (Pirie 1952, 1957)[3-4] so that only an outline of it need be given here (Table II).

From this it is clear that no new form of loss is introduced. Although not all the protein is extracted in a form suitable for people to eat, the part that remains with the fibre can still be fed to converters that would, in conventional circumstances, have had the whole crop. Ideally, the hope is to make separations so complete that every component finds a new and more efficient use, but something less complete than that is very useful.

THE DIRECTIONS, ECONOMICS AND MOTIVES OF BIOCHEMICAL ENGINEERING

This experience suggests the possibility of what it may not be too arrogant to call a general biochemical approach to the problem of getting more food. The techniques of biochemical analysis can define the presence in a plant of materials that should be useful; laboratory scale study and feeding experiments can show whether the materials are in fact as useful as we expect; and we can then see whether modern technology is adequate to get them out. The second is a vital phase, for analysis can only show the general nature of the materials present and not that they are useful. Many proteins, fats and carbohydrates are of little value in nutrition. Equipped with this knowledge, we can then search the plant kingdom for species that will grow exuberantly and that have been neglected hitherto because the techniques of primitive man were not adequate for the separation from them of useful components. It is well to remember that there are several hundred thousand plant species but only about a hundred contribute significantly to nutrition. Our choice is still unreasonably restricted by the whims and limitations of primitive man.

Protein is the main need but it is not the only one. Carbohydrate, though it seems at present to be relatively abundantly supplied by the starchy seeds and tubers and by sugar in cane and beet, could be made even more abundantly from cellulose. Plants make more cellulose than anything else, whether we think of yield per acre or of total world production. And cellulose, though useless in the simple digestive tract of animals such as man, is made up of glucose. There are many sources—bacteria, funguses and even molluscs—from which enzymes can be made that hydrolyse cellulose to give glucose, and among them we would probably find a good source of the enzyme for technological use. Here therefore is a promising theme for research. If organisms make the enzyme there is good reason to think that careful selection would give us especially productive strains, and that these could be used to hydrolyse the abundant supplies of cellulose in straw, wood and other materials that are unused, or at any rate not used for making food. The list of possibilities could be extended immensely.

When separation has gone to the present-day limit, the time honoured processes of conversion can be called in. But the converter should not be an animal that wastes foodstuffs in moving about and other activities. Rather we should turn to the micro-organisms, for they can operate with much greater efficiency. Yeasts are already grown on many by-products such as molasses and the sugars washed out during the processes of making wood pulp. This is a good beginning but it is not the end of the story. The useful micro-organisms would depend on green plants for their supply of carbon compounds and on our help for the supply of assimilable nitrogen and phosphorous compounds. The range of species that might be effective is enormous, and the search through this range has only just begun. Yeast has such an appeal because of its association with alcohol that some preoccupation with it is understandable, but the preoccupation can be carried too far.

Proposals such as these are often admitted to be biochemically sound, but they are held to be uneconomic because the materials made would not be as cheap as some of the existing types of food, even if we exclude foods to which we are accustomed, and that have a gustatory appeal. There are two answers to this objection. In the first place, it is well to be prepared; if all the bellies now in the world were filled there would be few surpluses anywhere—and the population is increasing. In the second place, we should examine the reason for cheapness and the amount of the cheap alternative that is available. A by-product that no one wants is always cheap. It may even have a negative value—that is to say, you may be paid to take it away. When a by-product has a use its price is, within limits, arbitrary. Two things are being made; the primary product and the by-product. The costs of the total operation are known, but the producer has discretion about how he divides the costs between the products. The history of chemistry gives many examples of a near waste gradually assuming importance; platinum, coal tar and uranium will serve as examples. Fish meal is more relevant. It is exceptional for a fisherman to go trawling for fish for meal. His object is to get fish for human consumption, and it is only what cannot be sold thus that goes to the meal factory. But this would not be so if the demand for meal became insistent. Unless people ate more fish the meal would have to carry the whole cost of fishing, and its cheapness would be seen to be spurious. Furthermore, a commodity that is cheap because very cheap labour is used in its production, as with many products of tropical agriculture, has a cheapness that is both unethical and ephemeral. Even if we disregard ethics, it is unrealistic to expect that great inequalities will persist between different parts of the world; especially if these different parts are being comparably fed. Myrdal (1957)[1] has discussed these and other factors pungently and in detail.

The committee that arranged this Armstrong Memorial Lecture suggested as a suitable title 'Food in relation to the Cost of Living'; that, as well as my own predelictions, may justify this excursion into superficial economics. In the title that I chose the words 'world hunger' were used deliberately, for this, rather than food supply, is the problem. Hunger depends both on the amount of food and on the number of mouths it has to go into. So far only the denominator has been

considered, but biochemistry has an important rôle in controlling the numerator too. It is not the business of a biochemist, nor of anyone else for that matter, to tell people what they ought to do or ought to want to do. But it is his function to explain what the necessary consequences of certain actions will be and to ask, perhaps with a note of suggestion in the question, whether in the circumstances they really want the things they think they want. In this discussion childbearing is the relevant activity, and the question would be, 'In getting all these children was fecundity or concupiscence the object?' If the former, then the biochemist's job is to produce the food; and at the present rate of population increase all the methods adumbrated here, and more, will soon be needed. But if the answer is 'the latter', then research on contraception should become a major biochemical preoccupation.[5] In my opinion—and this is a domain in which opinion has far outstripped fact—the graph of population against time is tending to become asymptotic with the population axis, not because of an increase in philoprogenitiveness, but because a radical change in survival, brought about by hygiene and medical services, has not been accompanied by a compensatory change in our other domestic habits. So much of the world's population is conceived inadvertently that if families contained no more members than were positively wanted there would probably be no food shortage. But this is not certain and, in any event, the food producers have no right to arrogate to themselves the control of human numbers; their job is to feed the number that is wanted.

From the question of what biochemical problems could usefully be studied we may turn to the more political question of the motives that might prompt a country to study them. Why should the U.S.A. put effort into this work when there is already an apparent surplus there of wheat, dried milk, and butter, and no reason to think that this state of affairs will not continue? For many reasons Britain is in a different position. Thus, in the U.S.A. (excluding Alaska) there are 12·3 acres of land per head, and 3·5 are used for agriculture. The figures for England and Wales are 0·8 and 0·55. There is more land per head in Scotland but a much smaller proportion of it is useable. We have been importing food for a century, and the scale of importation has been increasing, so that now we import more than half. For as long as our position as an exporting country was unchallenged this was economically advantageous; it helped to keep currency circulating. We have now lost this enviable position. There may be no reason to think that it will soon become impossible for us to pay for our food, but this is a possibility that must be recognized. More than any other country we combine an uncertain nutritional future with ample technological and research skill. Factors other than pure altruism should therefore prompt us to use more of this skill in finding out how to develop new sources of food, even although the most immediate beneficiaries of the research may live in less advanced countries.

Similar arguments apply in India. The need is there, and so is the scientific skill; to a greater extent than in most countries there is altruism, and India has many neighbours with an even greater need for food. Countries like Britain and India, with food problems of their own, can do little to help others by supplying food, but they can use their brains and skill for the public good.

SOME WAYS FOR EXTENDING BIOCHEMICAL ENGINEERING

Constant assertion that there is a shortage of scientists and money has misled many people into thinking that these are the serious obstacles to embarking on the sort of work outlined here. There will, of course, always be a shortage because it is in the nature of research to suggest new problems ripe for study and so to increase the demand for scientists. But, while we are waiting for more scientists to be trained, we might look at the existing sources of supply. The largest source of research skill is the inadequately used time and intelligence of the scientists already employed. Most scientists spend the greater part of their time doing jobs that people with a less expensive training could do better. The reason for this is that few laboratories have adequate workshop, secretarial and purchasing facilities (cf. Royal Society Council Report for 1957). This does not mean that the scientist should be insulated completely from the stresses of life. If he works with machines he should wrestle with them occasionally; and few things play more havoc with a literary style than dictation. But the stresses can be overdone, and generally are.

Next in importance among the ways of getting more research done is the removal of administrative obstacles. The most formidable intellectual problem that confronts an original scientist is to circumvent the people who are trying to stop him from doing his research in the proper way. There can be no question about what the proper way is; if the scientist was worth employing in the first place he knows it and will probably not be unwilling to explain it to others. This point has not escaped the notice of the thoughtful. Thus F. M. Cornford[6] said: 'There is only one argument for doing something; the rest are arguments for doing nothing. The argument for doing something is that it is the right thing to do.' And F. Nansen said: 'People say that I am very difficult to get on with; it's quite a mistake; only give me my own way and I'm the easiest fellow in the world to get on with.' (Mill, 1930.)[7] It is sometimes claimed that little harm is done by administrative obstruction, because anyone competent to tackle the intricacies of Nature can find a way through or round it, so that it is difficult for even the most expert committee man to stop completely research that gains his disfavour. We should not be too complacent about this; research may not be stopped but it can be greatly delayed and made excessively costly both in money and effort.

But, even after improvements along these lines have been made, more scientists will be needed, and the most obvious source of supply is diversion from other activities. We live in a capitalist society. The simplest guiding principle of such a society is that the esteem in which a person is held can be assessed by seeing what he is paid. All aspects of science are interesting, so that it is not unreasonable to expect alert scientists to move into those fields where they will be most esteemed. The pinnacles of the scientific profession, coming under Government control, show clearly which they are. It is not necessary to consider the relatively fabulous salaries of those concerned with nuclear phenomena; the old-established laboratories of the Department of Scientific and Industrial Research will serve for the purpose. Going through them alphabetically we find that the heads of

laboratories concerned with Building and with Chemical Research get £3,400 a year, whereas in laboratories concerned with Food and Forestry the maximum is £2,800 and sometimes it is even lower. With Radio and Road Research the figure rises to £3,400, only to fall back again with Water Pollution. That information comes from *Whitaker's Almanack*, which also tells us that the Chief Scientist at the Ministry of Power gets £4,250. Only one research laboratory in the financial control of the Ministry of Agriculture, Fisheries and Food, Veterinary Research, is listed in the £3,400 class. The affairs of the dozen or more Institutes coming under the Agricultural Research Council are shrouded in some, no doubt prudent, obscurity, but I am informed by the relevant professional organization that only one is in the £3,400 class.

No one is likely to have the temerity to argue that the lower-paid directors are intellectually inferior to the others; but if this should be argued, then the appointments policy needs reform, and it can only be reformed when the jobs have been equalized. Discrimination is perfectly clear, and it would be foolish for a young scientist, who wished ultimately to direct a laboratory and get a top salary, to come into biology. Salaries have been discussed here neither from simple, nor vicarious, cupidity, but because, as mentioned earlier, the salary is an index of the esteem in which a job is held; so that, although only a minority can hope to reach these top positions, they act as a lure controlling the choice of a career.

There is even discrimination among the different branches of biology. It is not as a rule possible to get unequivocal evidence for this from a study of the rates of pay in the lower reaches of the research profession, because merit and the character of the work are somewhat intangible. I had, however, the privilege of teaching several biochemists who are now employed by the Medical Research Council and the Agricultural Research Council, and so know something of their capacities. Systematically the pay is better under the M.R.C. and, to make assurance doubly sure, unlike the A.R.C. it pays family allowances. The prudent biologist would not veer towards food production, which gets rid of hunger, but towards medicine, which tends to exacerbate it.

Many of these points are made, though not quite so crudely, by the Council of the Royal Society in its Report for 1957.

> The productivity of the scientific research laboratories in our universities is less than it should be because of shortage of equipment and technicians. The lack of technicians is due to heavy competition from industry and from government scientific and medical services, the scales of pay in the universities being quite inadequate. . . .
>
> There may be danger that the development of physical science and engineering will lead to a neglect of the urgent needs of biological science. In its more conventional aspects biological work will become more expensive as more attention is given to the needs for field work, both at home and abroad, and to the supply of raw material—both plant and animal—in improved amount and quality. All biological sciences suffer from shortage of scientific and technical staff; the situation could be remedied by improvements in salaries and in superannuation arrangements. . . .

Agriculture is the Cinderella of the sciences, and biochemistry the Cinderella of agriculture. If these propositions were false the Agricultural Research Council would have more adequate accommodation and biochemistry would not be one of the worst, if not the worst, housed department in Rothamsted. This double disability, and the restricted finance that goes with it, makes progress slow and wasteful. For each line of work a certain amount of basic equipment is needed. Having got this it is folly not to keep it fully employed. This means that there is an optimum staff; with fewer than that expensive machinery lies idle, with more, people have to wait for one another. It is obviously possible to be thoughtlessly lavish; in other directions this is what we appear to be. For a tenth of the money that, in various parts of the world, is frittered away on useful or destructive nuclear phenomena, on sputniks, on radio, and so on, we could revolutionize the world's nutritional outlook. Even the 'practical man', whose hard head is so often used as a touchstone for new projects, is beginning to question certain aspects of conventional defence policy and economics. He may be becoming aware that Huxley and Keynes were right in calling him 'one who practises the errors of his forefathers', and 'the slave of some defunct economist'. The practical man should be replaced by the objective man who neither supports nor damns projects on principle but endeavours to get them tested; the failures then disappear. In this connection a classic comment, by the father of the Armstrong we have met to honour, may be recalled: 'Hypotheses are like scientists, they should disappear when they are seen no longer to work in the laboratory.'

But even with extended funds there must be some canon by which projects are judged. It might well be quantitative and take the form of a question. 'Let us suppose that the research justifies expectation and brings about the changes in practice that have been forecast. What will be the total advantage to humanity measured in money or, preferably, in extra food available?' Clearly those projects for which the biggest claims are made, with a little allowance for enthusiasm, deserve the most careful study. It often seems at present as if effort and importance are not well matched; wheat gets little more attention than pleasant but inessential fruits such as the strawberry, and as much attention is paid to things like the quality of cider as to a major source of protein.

John Stewart Mill said that 'Englishmen habitually distrust the most obvious truths if the person who advances them is suspected of having any general views'. The experience of those concerned with world food supplies amply bears this out. Thus in the 1930s the obvious fact that many of the inhabitants of Britain and most of those of the World were underfed, was disregarded and dismissed as a bit of Socialist propaganda. Those of us who pointed the fact out were labelled, irrelevantly though perhaps correctly, Socialist propagandists. As you have seen, I am still addicted to general views; but in spite of that the facts are there.

The Lecturer then pointed out that he had brought with him leaf protein in various forms—biscuits, ravioli, cromeskis, freeze-dried powder and solvent extracted

powder—and urged those members of the audience interested to sample them after the meeting.

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DISCUSSION

THE CHAIRMAN: I think Mr. Pirie has been deliberately provocative because he enjoys discussion after his lectures! I should like to take up one or two points he made in his very interesting paper. In relation to heat production, he mentioned the question of intelligent siting of wind breaks. This reminds me of what a scientist who has been working in the polar regions recently told me: that it is estimated that for every one mile per hour of wind there is a drop in temperature of one degree. So that a wind of thirty miles in the polar regions causes a drop in temperature of as much as thirty degrees. That obviously bears out the point which Mr. Pirie made in relation to wind breaks.

He mentioned also the question of irrigation. As you know, in the last few years in Ceylon they have opened up some of the old irrigation systems which were built perhaps a thousand or more years ago, and have developed them very considerably with a resulting increase in productive land. Mr. Pirie said that only one-twentieth of the food in the world was produced as a result of engineering schemes involving irrigation and the like. He also told us that it is possible to de-salt the seas. That seems to me to be a line on which much more could be done, provided we remember Mr. Pirie's warning of possible dangers from nuclear radiation.

With regard to fertilizers: as you know, Lord Douglas of Garloch is a great champion in this country of the better use of human soil by composting with vegetable wastes. That is done, of course, in China and other countries on a large scale. The process needs careful control, otherwise it may be dangerous because of the intestinal parasites and organisms that may be present in crude, untreated sewage.

The growing scarcity of scientists and biochemists and the need to give them better salaries is a matter of great concern. But I feel that despite the fact that we have a Welfare State and that we are looked after 'from the womb to the tomb', a great many of us do become engine drivers, or sweet-shop keepers, doctors or even biochemists, simply because that is what we want to do, regardless of the amount each activity brings into our weekly paypacket. I like to think that that vocational interest does survive despite two world wars.

In relation to our faulty world distribution of food supplies I should like to tell you a story. In the early part of the Depression, in the early 1930s, a rather serious flood affected the Yangtse Valley, and I was asked to go and advise on the care of refugees who were pouring in tens of thousands into Shanghai from the Yangtse Delta. Unfortunately there was not enough money to give the refugees anything better than shacks to live in; and for food what amounted to a rather thin rice porridge, called 'congee', which was a quite inadequate diet by itself. After leaving Shanghai, I happened to call in at Hawaii, and there I found they were dumping all their pineapples in order to avoid glutting the market. Thence I travelled via Los Angeles up through the Yosemite Valley to Seattle and Vancouver, and on the way I went through the vast Delmonte Plantations. Here, they were deliberately allowing all the fruit (except nectarines, for which, apparently, there was a market) to fall and rot on to the ground. Then as I made my way across the Rockies and over the prairies,

I saw them ploughing in the wheat because it would only fetch 67½ cents a bushel. When I arrived at New York I witnessed long queues of men, women and children, waiting for a bowl of soup and a piece of bread each for the day. So at each end of my journey—Shanghai and New York—there was near-starvation and in between people were deliberately destroying food. Even in recent years we have heard of food—potatoes, butter and coffee, for example—being destroyed in large quantities simply because of the state of the market. So I think there is much to be said for a better system of food distribution. We import into this country (and so they do into America and Europe) quite large quantities of phosphates from the Southern Pacific and from places like the Seychelles. Could we not make our own instead and release that fertilizer we would otherwise have imported for countries like the Indian sub-continent where they lack facilities for making satisfactory fertilizer? I ask Mr. Pirie whether, in fact, he thinks we could not achieve some of the results that he is aiming at by improving the system of distribution?

The last point I should like to make is this: it lies very much in the hands of scientists whether we devote our efforts to trying to improve the very unsatisfactory dietary of so many human beings, by concentrating on the constructive possibilities of nuclear energy rather than on their destructive powers.

THE LECTURER: I can agree wholeheartedly with your final statement, that the sooner we can stop all the destructive activities the better. Distribution is a large subject. Before the war the world's largest merchant navy, our own, was to a large extent occupied in feeding forty-odd million people. The problem of feeding any sizeable population by bringing food from other parts of the world is a sizeable one. I do not want to advocate King Solomon's conception of world trade, but it is a rather better conception than that which involves having your main food supplies exposed to the vicissitudes of world trade. And although the more acute examples of waste are obviously shocking, I doubt if it is feasible to feed any country much bigger than this by shipping food direct from overseas. Furthermore, although surpluses look very spectacular, the U.S. wheat surplus in 1955 was equivalent to less than one year's consumption, and the Secretary of Agriculture, Benson, said that three merely poor (not ruined) crops in succession would wipe out the wheat surplus. The margin is as small as that. So although I entirely agree that food should not be thrown away, I doubt the feasibility of carrying the basic foodstuffs for any large populations round the world.

I also agree that most of the world's best work is done by underpaid, harrassed people who do it because they like it; but if you are already conscious of a shortage of men in certain fields, either you abolish the capitalist system or you play according to its rules, which, as I understand them, are that when you want something done you devote money to it. My thesis was that we need more biochemists and other sorts of biologists. We get some by existing methods. If we need any more the economic approach should be tried.

MAJOR W. V. G. FUGE, M.B.E.: May I ask the lecturer whether there is any hope of developing an economic chemical process for converting cellulose into a protein suitable for human consumption?

THE LECTURER: Probably not, if you mean a wholly synthetic chemical process, because the problem is to get the nitrogen into it. The complete synthethis of amino-acids will, for the foreseeable future, be a good deal more expensive than letting an organism, yeast or bacteria or fungus, do it for you. It is a job they do extremely efficiently and quickly and so I think I can leave the making of protein to them. But we might use cellulose as a main source of carbon. If we work, as I suggested we should work, on enzymes, we could split the cellulose and so make a medium on which these organisms could grow with the help of ammonia made by fixation.

DR. FRANK WOKES (Director of Research, Ovaltine Research Laboratories): Mr. Pirie has mentioned the lack of pulses in this country. It is true that soya, which is a very good source of protein, vegetable protein, does not grow well in the country so far as we can ascertain, but I should like to make a plea for peas. Growers in Lincolnshire have told me that they could produce far more peas if there was a demand for them, and there you have also, of course, the improvement to the soil through fixation of atmospheric nitrogen. Another point with regard to peas which I think might be looked into, is utilizing something else besides the pea itself. There are the pea-pods, and the leaves and so on, which could form perhaps a useful form of protein.

THE LECTURER: They not only could, they do. One of our chief raw materials for making leaf protein is the pea-vine, the waste from pea canneries, and from peas cut young for quick freezing. But the yield of protein from peas, when you cut them young, is very low. I have not got any figures, but if it amounted to more than 100 pounds of protein per acre I should be surprised. Even field beans give only a ton of beans under good conditions, and the yield is often lower than that. But I agree that more legumes could and should be grown, especially if we can make protein from the leaves and stems.

DR. DOUGLAS LATTO: The last time I spoke to Mr. Pirie he told me that the body stood up very much better to privation than to excess. Has he changed his mind?

THE LECTURER: No. But I do not look on 2,700 calories as an excess—that is what you and I get. If a person got only 2,200, he would be underfed unless he was very small. That is a reduction of 500 calories from what I regard as normal, but people often live for sixty years or more on as low a diet as that. If, on the other hand, the intake is 3,200 calories for long periods, that is a 500 calorie excess, the prospects are not so good. That is what I meant.

MISS D. F. HOLLINGSWORTH, O.B.E. (Ministry of Agriculture, Fisheries and Food): I am going to ask Mr. Pirie a question which I have asked him before: could he explain how he thinks a green protein could be used in the diet in the parts of the world where it is needed?

THE LECTURER: Well there are many ways. Firstly, why do you not like proteins to be green? Simply because you are unaccustomed to it—and if I may say so, gently —a little bigoted about the colour of proteins. This is an old argument. People eat foods of various colours and so far green has not been a common one. But it might be. It is just a matter of education, and the easiest way of starting that education is to begin young. One of the main nutritional problems of the world is, as you know, *kwashiorkor*, which is in part protein-malnutrition of young people in tropical areas. There is often abundant leafy material in these areas, and we should try to make and use leaf protein there. This obviously requires experiment, but I doubt if children would complain any more than they complain about other new foods. The fact that it was green would not bother them, and then later in their lives we should have a group of people who had accepted a green food without more ado. So one answer to your question is, that if the people we now have to cater for will not eat a green food, we must bring up a group who will! The other way is to conceal the green colour.

DR. H. B. FRANKLIN: I should like to ask Mr. Pirie if the leaf protein will autolyse spontaneously into amino-acids very much in the same way say that yeast and other forms of protein will?

THE LECTURER: No. Most leaves have little proteolytic activity. The only exceptions are the leaves, like fig and some spurges, with latex in them, and these we have not

tried as sources of protein. What little protease there is in the leaves we use is probably destroyed during the heat coagulation of the protein. But the protein can be digested by some other enzymes, pepsin and trypsin, for example, or by acids. Experiments on its digestion *in vitro* are being carried out now in parallel with experiments on its nutritional value.

MR. SPENCER (National College of Food Technology): Mr. Pirie proposes that the green leaf protein extraction should take the place of the conversion into things like milk and meat. But milk and meat are good carriers of vitamins, and how does Mr. Pirie propose to make up for this? Does his process of extraction include the extraction of important vitamins or is there some other proposal for dealing with some of the by-products during manufacture?

THE LECTURER: As you remember, that was part of the scheme in Table II [on page 517]. There is the fibre residue as well as leaf protein, and that would be fed to ruminants. One probable result of the large-scale adoption of a policy of making leaf protein in Britain might be an increase, rather than a diminution, in the number of cattle, because there would, for the first time, be a real incentive to fertilize grazing land intensively. To make protein we have to start with a high-protein leaf. The protein before solvent extraction has vitamins A and D in it. Vitamin C and the B group are washed out, but there are alternative sources of these.

MR. SPENCER: What about vitamin B_{12}?

THE LECTURER: B_{12} is not present in quantity in most parts of an animal. It comes from the liver mainly. Streptomyces makes it very efficiently, and that is an organism that it should be possible to grow on the fluid mentioned in Table II. But this is a matter for experiment.

DR. D. F. EVERED (Department of Biochemistry, London Hospital Medical College): I understand that the problem in many under-developed countries is not an absolute lack of protein but rather a lack of first-class proteins, namely, those obtained from animal sources, peas, beans, and other legumes. Diets rich in vegetables seem to be short of the essential amino-acid, methionine, and those derived from cereals seem to be short of lysine. Can Mr. Pirie perhaps tell us whether his leaf protein is particularly rich in these important nutrients?

THE LECTURER: Leaf protein is a good source of lysine and a bad source of methionine. In its methionine content it is as good as most other seeds, as good as the wheat protein, and as good as many cuts of meat, but it is not as good as the two extreme proteins, casein and egg white. They are often looked upon as the standard proteins in nutrition, but they are exceptionally good. Now it is interesting that one of the better sources of methionine is the protein from certain strains of maize, because although the protein content of maize is often low, 8 or 9 per cent (sometimes as high as 12 per cent), its methionine content is more than 3 per cent. So a maize and leaf protein mixture should be quite a well-balanced one, and a diet which includes fish would also go well with leaf protein because fish is rich in methionine too. What we need more than any other kind of food is a good methionine source which you can grow. Nobody has searched properly yet; there has been a little work on maize, which I spoke of, otherwise the field has hardly been surveyed at all. Various yeast bacterial fungal proteins have hardly been looked at. I do not believe many of the published figures because methionine is one of the more difficult amino-acids to determine. For example, there was a phase when people spoke well of sun-flower seed protein as a methionine source. It now appears that it is not. Sun-flower seed is not better than most other seeds of the same sort. World-wide methionine hunting is a further important field for biochemical research.

DR. VERNON CHARLEY: May I ask Mr. Pirie if he is making efforts to start his process at the present time in any country in the world where the need for leaf protein is great and they have the raw materials to produce it?

THE LECTURER: Effort perhaps is not the word, because I have not yet actually got something to offer anybody. If the government, let us say, of British Guiana (which appears to be an underfed region with abundant vegetation) asked me to erect a protein-making plant there, I could not do it yet. All I know at the moment is how to make it on a large laboratory scale. What we want to do is to set up an experimental unit in a region like British Guiana and see how it works. That is the next important step. My skill, if any, is in making the protein, not in organizing the campaign to get the factory started.

THE CHAIRMAN: If Sir John Russell were here this evening he would no doubt sum up most ably, and in his absence I do not propose to attempt it. I should just like to thank those who have taken part in the discussion, and say to Mr. Pirie on your behalf how very much we have enjoyed his address and how grateful we are to him for the trouble he has taken in preparing it, and for giving us the most interesting demonstrations.

The vote of thanks to the Lecturer was carried with acclamation, and the meeting then ended.

INDUSTRIAL POWER OF THE FUTURE

The Trueman Wood Lecture by

SIR CHRISTOPHER HINTON, K.B.E., F.R.S.,

Chairman, Central Electricity Generating Board, *delivered to the Society on Wednesday, 19th March, 1958, with Sir Alfred Bossom, Bt., LL.D., F.R.I.B.A., J.P., M.P., Chairman of Council of the Society, in the Chair*

THE CHAIRMAN: I have no doubt we all recognize that we are enjoying the experience of living in an age of great change, and nothing is exposing that condition more forcibly than the change that has taken place in the source of industrial power. Atomic energy is the power of the future and to no one should we listen with more respect on this subject than to Sir Christopher Hinton.

The following lecture, which was illustrated with lantern slides, was then delivered:

THE LECTURE

Since the War, two of your Trueman Wood lectures have dealt with the industrial applications of nuclear energy. In the first of these, given by Sir Charles Ellis in 1946, he gave a wise and reasonable warning that a great deal of work had to be done before industrial application of the new force could be expected. When Professor Oliphant spoke to you on the same subject in 1950, he said 'Industrial power from uranium is on the doorstep'. This was indeed so and it arrived in 1956 when the first supplies of electricity were switched by the Queen from Calder Hall into the distribution network of the Central Electricity Authority.

I propose to-day briefly to review the steps by which this was achieved and to see what atomic energy holds for us in the future.

Let us first of all refresh our memories on the way in which we obtain heat from nuclear fission (Figure 1). The phenomenon takes place only in one atom which exists in nature, namely the atom of an isotope of uranium with an atomic number of 235. When the nucleus of this atom is struck by a neutron, the whole complicated solar system of the U. 235 atom breaks down and forms two separate solar systems; new atoms of almost any of the elements about the middle of the periodic table. Generally the energy content of these new atoms is smaller than the energy content of the initial atom of uranium 235, and the difference between this initial energy content and the energy content of the atoms which exist after fission is emitted as heat. As in so many nuclear reactions, the amount of heat given off is very large as compared with the heat which can be given off by carrying out chemical reactions with similar quantities of material.

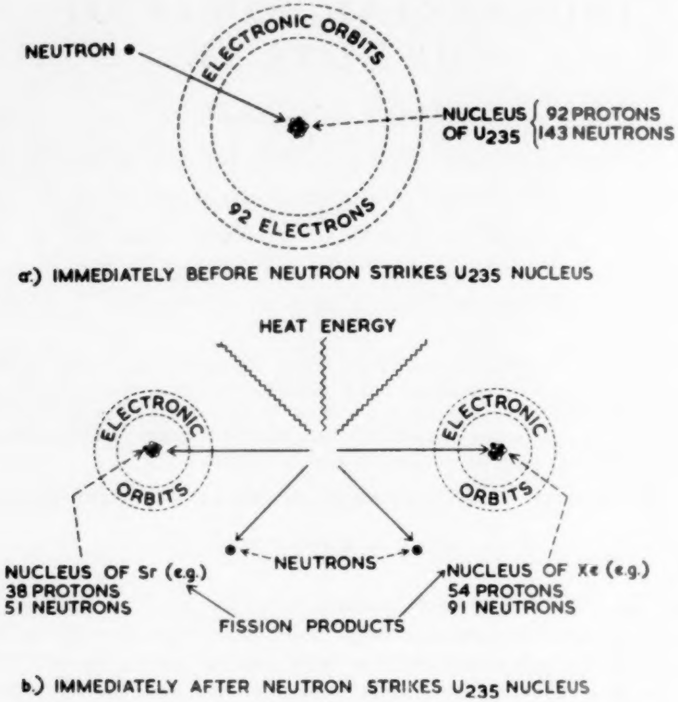

FIGURE 1. *Illustration of fission*

When fission takes place, not only is heat evolved but also a number of neutrons are emitted; this number is variable, but on average it amounts to rather over $2\frac{1}{2}$ neutrons per fission. Thus, having caused fission by using one neutron as a missile to bombard the nucleus of an atom of uranium 235, we obtain from this fission not merely our heat but a number of neutrons which can be used to continue the reaction.

In natural uranium only 0·7 per cent of the atoms are those of the fissionable isotope U. 235. The remainder are those of another isotope having an atomic mass of 238. These atoms of U. 238 are not fissionable; when a neutron strikes them it is absorbed to form first an unstable isotope U. 239 which, by a process of beta particle emission, forms first of all an unstable artificial element called neptunium and then the stable radioactive element plutonium (Figure 2). Plutonium, like uranium 235, is fissionable.

It is by making use of these characteristics of the mixture of isotopes which exist in natural uranium that we can operate nuclear reactors of the type which are used at Windscale or Calder Hall. When a neutron strikes an atom of

NATURAL URANIUM CONTAINS

$0{\cdot}7\%\ U^{235}$ IE. ONE ATOM OF U^{235}
$99{\cdot}3\%\ U^{238}$ TO EVERY 140 ATOMS OF U^{238}

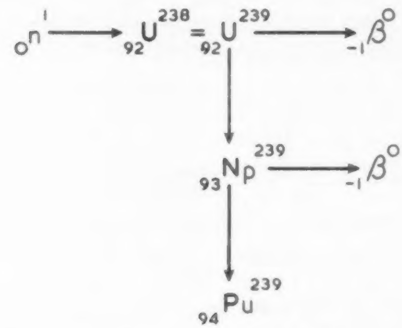

FIGURE 2. *Stable radioactive element plutonium*

uranium 235, heat is emitted and fission products are formed. Neutrons are also emitted and some of these will be uselessly absorbed and lost in materials of construction. We can assume that from each fission we may have two neutrons left. One of these we can use to bombard an atom of uranium 238 with the ultimate formation of plutonium, while the other we use to bombard an atom of uranium 235, causing a further fission which enables us to continue our chain of reaction (Figure 3). But the relative number of atoms of U. 238 and U. 235 in natural uranium make it improbable that we shall be able to secure the distribution which is required for the chain reaction shown in Figure 3, since there is a statistical probability that most of the neutrons will be absorbed in the more numerous atoms of U. 238, and an insufficient number will strike atoms of U. 235 and cause further fissions which enable the chain reaction process to be continued.

This probability can be rectified if we slow the neutrons down. When they are emitted they are travelling at very high velocities, but by allowing them to collide with atoms of a suitable material called a moderator, they will share their energy with the atoms in the moderator until they are reduced to velocities corresponding to the temperature of that moderator. Neutrons travelling at these thermal velocities are more likely to cause fission in atoms of uranium 235 and less likely to be absorbed in atoms of U. 238. By a correct dispersion of natural uranium in a moderator (which may be graphite, hydrogen or beryllium) we can secure the necessary distribution of neutrons to enable us to carry out the chain reaction which we see in Figure 3.

We have already seen that we are bound to lose a number of neutrons from our system, this loss occurring partly by useless absorption within the system and partly by radiation of neutrons outside it. The external radiation of neutrons will be proportional to the surface area of our assembly, whereas the number of neutrons available will depend on its volume. It follows, therefore, that the larger the assembly the smaller will be the percentage of the neutrons which is lost. If our assembly is below a certain size, we shall lose so many neutrons by escape from the surface that the reaction cannot be continued. If it is above a certain size, we shall have spare neutrons which will enable us to build up the

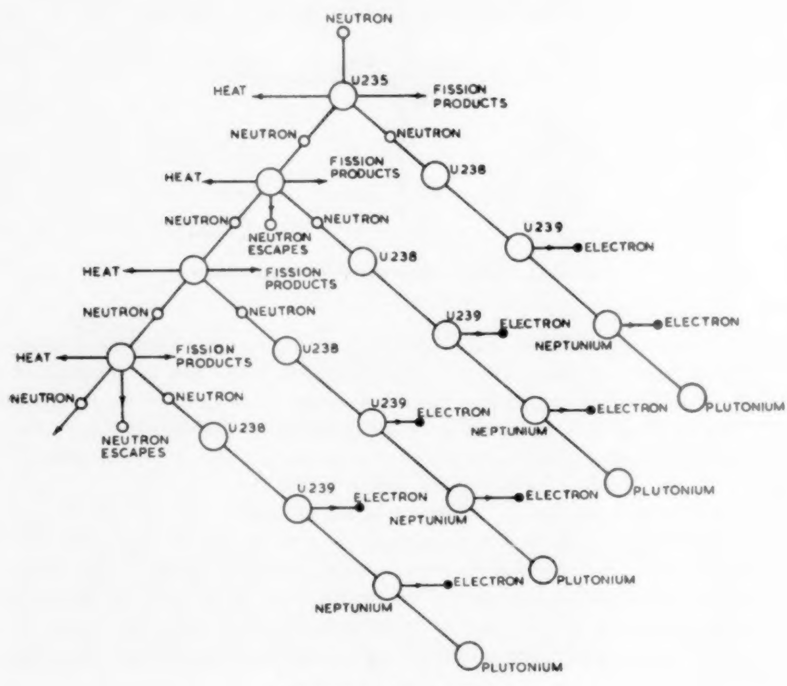

FIGURE 3. *Chain reaction*

activity within it. Practical reactors are always designed to be above the 'critical size'. The spare neutrons which are then available are used for building up the activity in the assembly, and when this activity has reached a specified level, further growth of activity must be prevented by absorbing these excess neutrons. This is done by pushing rods of a neutron-absorbing material into the reactor.

We thus see in the simplest possible terms what we need in order to build an atomic pile. We must have an assembly containing a sufficient quantity of uranium embedded in a moderator. We need rods of neutron-absorbing material in order

to control the level of reaction and we must have some way of removing the heat of fission. The reacting core will have great radioactivity, and in order to shield the operators from its effects, the system must be enclosed in concrete of sufficient thickness to reduce the activity to a level which is biologically tolerable.

It is obvious that by arranging our uranium in this way, we can use it as a fuel, that is, a material from which we can produce heat. In order to convert heat into other forms of energy, however, it is not merely necessary to have an appropriately large quantity of heat; this heat must be at a sufficiently high temperature. When we built the first industrial reactors at Windscale, our primary objective was the production of plutonium for defence purposes. The release of heat in the Windscale reactors was inevitable, but at that time our knowledge was not sufficiently great to enable us to recover this heat at a high enough temperature to generate useful electrical power from it, and the heat from the Windscale piles was, therefore, wasted to atmosphere.

When additional plutonium production capacity was sanctioned in 1953, the technology had advanced sufficiently to enable us to achieve higher temperatures, and by recovering our heat of fission at these higher temperatures we were able to make use of this heat to generate electrical power, and this was done in the Calder Hall reactors. In these, the heat of fission is removed from the core by circulating carbon dioxide under pressure through it, and the carbon dioxide, heated in this way, is cooled in boilers; there it gives up its heat to the water and forms steam, which is used in conventional turbo-alternators.

While Calder Hall was still under construction, it was realized that reactors of this type could be built for industrial use and operation by the Electricity Authorities. At Calder Hall, the primary product is plutonium, and electricity is produced only as a by-product. By making slight modifications to the design, it is possible to optimize reactors of this type for the production of electrical power; if this is done, plutonium is produced as the by-product. Because this by-product plutonium is a fissile material, it can potentially be used as a fuel in suitable reactors just as the fissionable U. 235 is used as fuel in the Calder Hall reactors. It is indeed possible to use plutonium in reactors of this type, but it is better to use it as a pure or only slightly diluted fissile material in what is called a Fast Reactor. It will be remembered that in reactors of the Calder Hall type using natural uranium as a fuel, the neutrons are slowed down by the moderator so that the chain reaction will be maintained and so that an undue proportion of the available neutrons will not be absorbed in the unfissionable uranium 238. But if a pure or nearly pure fissionable material is used as the fuel in the reactor, it will be unnecessary to slow the neutrons down in this way because there will be no danger that an undue number of them will be absorbed without causing fissions. It will then be possible to continue the chain reaction by using neutrons whose velocity has not been moderated. Reactors in which this is done are called fast reactors because the neutrons are not slowed down from their initial velocities. Because no moderator is present the neutron economy is better, and by inserting suitable 'source material' (i.e., materials like U. 238 which can form fissile materials by absorbing neutrons) in the reactor in such a way that they may

absorb the surplus neutrons, we can form within the reactor more fissile material than is destroyed by combustion of the nuclear fuel.

It is then possible to visualize an integrated programme for the industrial use of nuclear power in which we generate electrical power using natural uranium as a fuel in reactors of the Calder Hall type. These reactors will produce plutonium as a by-product, and this by-product plutonium can be used as a fuel in fast reactors, where it also generates electrical power and at the same time creates still more plutonium.

The possibilities of such a programme were envisaged while Calder Hall was in its early stages of construction, and a detailed plan was prepared. This was ultimately published in the form of a White Paper in February, 1955, and set out a plan in which twelve nuclear power stations were to be built by the Electricity Authorities and put into operation by 1965. These twelve power stations were to have a capacity of between 1500 and 2000 MW and would save between five and six million tons of coal a year.

The orders for the first two of these stations were placed by the Central Electricity Authority at the end of 1956 (Figure 4—Bradwell). The estimated cost of the power produced from these stations amounts to 0·66 pence per unit of electricity sent out. This is higher than the cost at which electricity can be generated in the most modern power stations using conventional power, and the construction of these initial stations must, therefore, be justified not by what they themselves are able to achieve, but rather by the developments which they are likely to lead to.

Let us then look at these developments and see what sort of a future we can predict for nuclear power.

In terms of real money values, the capital cost of power plants using conventional fuels has come down steadily since the end of the eighteenth century when they were first built, and their efficiency has risen. More than anything else this reduction in the cost of steam power plants has been linked with the rise in the initial temperature which it has been possible to achieve in the steam cycle. The limit has been imposed by different factors at different times; in the earliest days, it was controlled by the pressure which could safely be sustained in cast-iron vessels, later it was limited by the performance of cylinder lubricating oils in reciprocating engines, but for the last forty years it has been controlled mainly by the metallurgy of the materials available for superheater, steam pipe and turbine construction. James Watt's engines working at atmospheric pressure consumed 6 lbs. of coal per horse-power hour; to-day the modern steam generating plant consumes only $\frac{3}{4}$ lb., and this rise in efficiency has sprung almost entirely from the rise which has been possible in the initial temperatures in the heat cycle. But the rise in initial temperature has done more than raise the theoretical and practical efficiency; it has made it possible for higher working pressures to be used, and this in turn, operating hand in hand with other developments, has made it possible to build bigger boiler and turbine units, and it is this growth in unit size and rating which, more than anything else, has brought down capital costs (Figure 5).

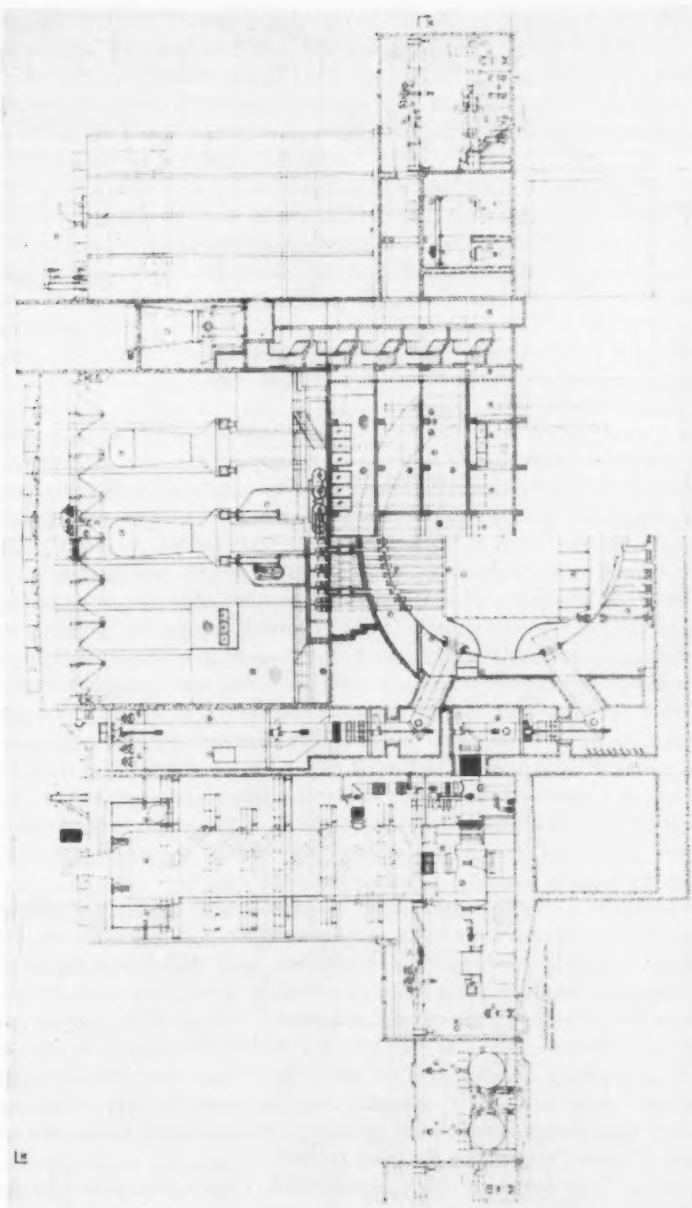

FIGURE 4. *Cross section through Bradwell reactor No. 1*

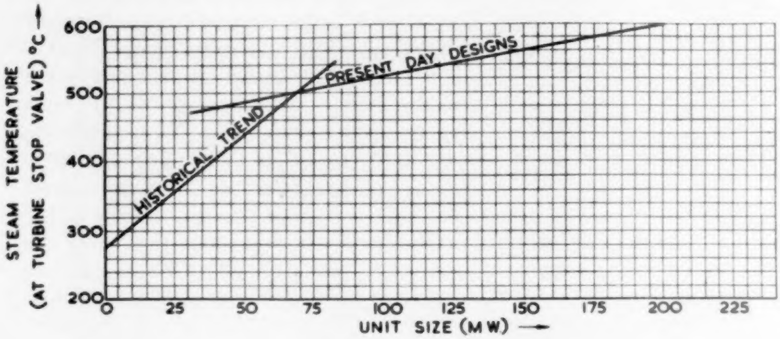

FIGURE 5. *Rise in steam temperature and unit size with passage of time*

We have already seen that when we designed the Windscale reactors we were not able to recover our heat at a temperature high enough to enable us to generate useful power. Yet even these Windscale reactors used far higher operating temperatures than those which we had achieved in the large experimental reactor which we had built at Harwell only two years before. At that time the operating temperature which we could achieve in our reactor was determined by the performance which we could expect from our fuel elements, and this will be the case for many years to come. In the Windscale reactor the fuel elements consisted of uranium rods, just under an inch in diameter, enclosed in aluminium cans. It was known that aluminium and uranium could form a compound which would cause perforation of the can and that the formation of this compound proceeded more rapidly the higher the temperature of operation. It was known also that under the conditions which exist in the reactor there is growth of the uranium metal because of changes in the crystal shape under irradiation, and it was known that these changes in configuration of the uranium might cause breakdown of the fuel elements. It was these considerations which prevented us from recovering the heat at a higher temperature.

When we started the design of the Calder Hall reactors, we had more knowledge of this problem of uranium growth and more confidence in our ability to deal with it, but the most important advance which was made at that time was to use a magnesium alloy as the canning material instead of aluminium. Uranium and magnesium do not form an inter-metallic compound, and one of the most serious possibilities of failure in the fuel elements is therefore eliminated. It was this change to magnesium canning, and growth of knowledge in other directions, which enabled us to step up our operating temperature to the level which was adopted at Calder Hall, and which was sufficiently high to enable us to make use of the heat of fission to generate electrical power.

Since Calder Hall has gone into operation, orders have been placed by the Central Electricity Authority for the reactors which are being built at Berkeley

and Bradwell, and in these reactors still higher temperatures have been adopted although the fuel elements are generally similar to those which are used at Calder Hall. The outlet temperature of the coolant gas from the reactors determines the top temperature which we can achieve in our heat cycle. This in its turn determines the efficiency of the heat cycle and the nature of the plant used—the higher the temperature the more efficient is the plant. The upward trend of these temperatures is shown in Figure 6.

If we are to continue to improve nuclear power plants in the future, as we have done in the past, we must go on raising our top temperatures so that (subject to the normal departures from a smooth trend curve) the temperatures achieved continue the upward slope which has been achieved hitherto.

It is towards the solution of this problem that a very large part of the research programme of the Atomic Energy Authority is directed. It is doubtful whether appreciably higher temperatures can be achieved while using magnesium as a canning material for the uranium, because the melting point of magnesium is only a little over 600°C. Other canning materials having higher melting points are zirconium, which is not particularly suitable for gas cooled reactors because it is chemically attacked by CO_2 at temperatures over 500°C, or beryllium. We could in all probability achieve outlet gas temperatures of about 430°C by using beryllium as a canning material with metallic uranium as a fuel, but in order to achieve temperatures even higher than this we shall have to dispense with the use of metallic uranium and use instead a ceramic compound of uranium such as oxide, the carbide or the silicide. By doing this, it should be possible to achieve outlet gas temperatures of about 500°C. But the development of fuel elements of this sort demands a tremendous amount of experimental

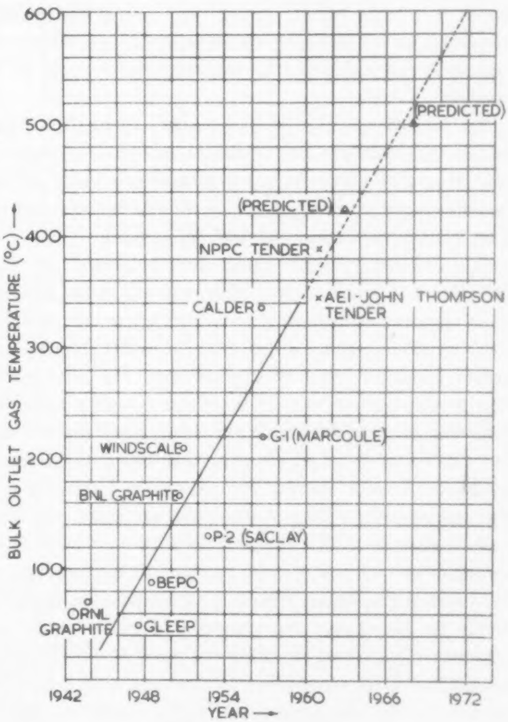

FIGURE 6. *Rise in outlet gas temperature with passage of time*

and development work, and before they could be incorporated in the design of an expensive full-scale nuclear power station it would almost certainly be necessary to carry out a prolonged test in an experimental reactor. It is, therefore, quite probable that fuel elements of this type will not be widely used in industrial reactors until the late 1960s.

The use of higher temperatures will give rise to many other problems. For instance, the coolant gas which is at present used is carbon dioxide, and this reacts chemically with the graphite moderator at high temperatures. The rate of reaction may be accelerated by the intense neutron bombardment of the graphite in the reactor; it can possibly be alleviated or cured by the use of graphite which has been chemically treated with an immunizer.

Higher temperatures also induce problems in connection with the construction of the pressure system. Because the main pressure vessels have to be fabricated on site by reason of their large size, the steel of which they are made has to have characteristics which make it immune from brittle fracture. But, in order to withstand high operating temperatures, it must also have good creep resistance. The problem of selecting suitable steels becomes more acute as the temperature rises; it may be solved by evolving new steels having the special characteristics required, or by adopting engineering layouts which will ensure that the pressure casing is not subjected to the full temperature of the coolant gas leaving the reactor.

As we achieve higher temperature in nuclear reactors, and therefore higher initial temperatures in the heat cycle which is used for generating power, we shall find that higher steam pressures are used, and this will reduce (for a given power output) the physical size of the boilers and turbines, while at the same time leading to higher thermal efficiencies.

Simultaneously with these developments, we can expect increases in the rating of our fuel elements, that is to say in the rate at which we can extract heat from each ton of fuel in the reactor. Obviously if this rating can be doubled, we shall be getting twice as much heat and approximately twice as much potential power from a reactor of a given size, and this will naturally halve the capital cost of this particular section of our power plant. The ratings which have been achieved in the past have been determined by our ability to get heat away from the surface of the fuel element into the coolant gas. In the Windscale reactors which used air at atmospheric pressure for cooling, the heat transfer was poor and the specific rating of the fuel elements was low. In Calder Hall we used carbon dioxide under pressure as a coolant, and this naturally gave better heat transfers and better specific ratings. In the reactors that are being designed for the Central Electricity Generating Board even higher ratings are being achieved, partly by increasing the pressure of the coolant and partly by increasing its velocity. We are now reaching the point at which the specific rating is determined not so much by our ability to conduct heat away from the surface of our fuel element as by the conditions in the centre of that fuel element. The heat of fission is generated through the whole cross section of the fuel, and it has to be conducted from the centre of the fuel element to the surface from which it is

removed. In order that the heat may flow outwards from the centre to the surface there must be a temperature gradient across the fuel element, and the temperature at the centre of the fuel element must be high enough to give the rate of heat flow which is necessary. Thus, the higher the heat flux the bigger the temperature difference between the surface of the bar and its centre. We have already seen that we must raise the outlet gas temperatures which we achieve in reactors, and this necessarily demands higher fuel element surface temperatures. If on top of this we superimpose higher ratings so that we get bigger temperature gradients over our cross section, we find that we are approaching the point where, with fuel elements of the form used at Calder Hall, the centre temperature of the uranium would be dangerously high. To some extent this can be remedied by using fuel elements of smaller cross section, but ultimately

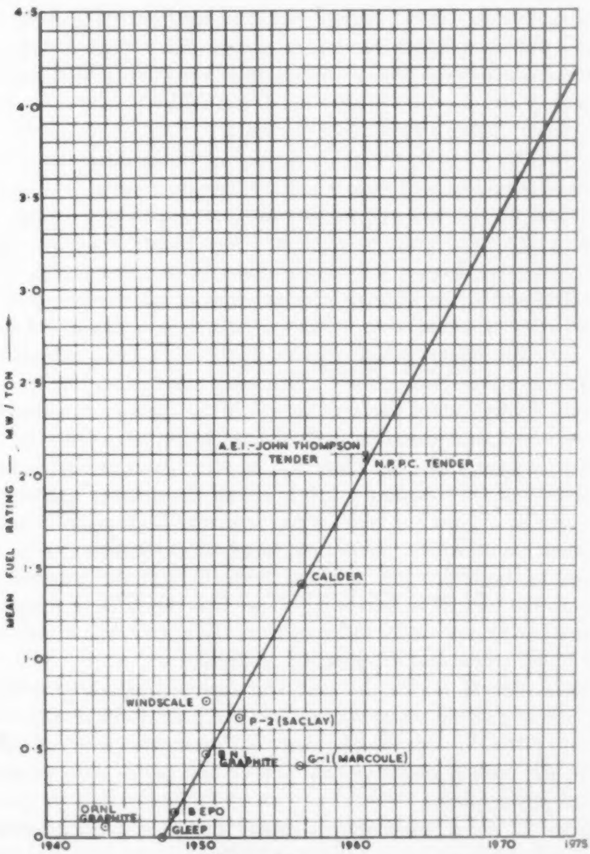

FIGURE 7. *Rise in fuel rating with passage of time*

the solution once more lies in the use of ceramic fuel elements in which the temperature at the centre of the element can be taken to a very high level.

Figure 7 shows the way in which fuel element ratings have increased in the past and the trend which must be aimed at in the future if reactor development is to continue at its present pace.

We see, therefore, that progress demands that research and development work should enable us to continue scrambling up the trend curves towards higher top temperatures in the heat cycle and higher specific ratings of the fuel elements. Both these developments demand the use of ceramic fuels, and this use of ceramic fuels makes it necessary to enrich the fuel in order to secure the nuclear characteristics which are necessary in the core. But these enriched fuel elements using a costly material such as beryllium for canning will be expensive, and we shall find that their use will only be justified if we can achieve high burn-ups, that is to say they will be justified only if we can leave the fuel element in the reactor for a sufficient length of time to ensure that a high percentage of the fissile material which it contains is burned up before the fuel element is removed from the reactor for chemical processing. It should be possible to achieve these high burn-ups by using ceramic fuel elements.

Looking backwards over the short history of nuclear reactors and forward into that short period of the future which we have been endeavouring to forecast in this section of the lecture, we are able to establish a rough trend for the reduction in capital costs of nuclear power plants which we can hope to achieve by achieving higher top temperatures in our heat cycle, higher fuel element ratings and higher fuel element burn-ups. It is interesting to see how the downwards trend of capital cost which we have thus endeavoured to establish compares with the figures which history shows have been achieved in other forms of prime mover during their much longer histories. Figure 8 shows in terms of real money values the way in which the costs of conventional steam power stations and land-based oil engines have come down with the passage of time. It is, of course, clear that there will be some point at which these curves tend to flatten out. On the same graph is shown the trend of capital cost which we believe can be expected in nuclear power plants. This trend is based on the sort of analysis described in this lecture, in which the improvements which can be envisaged in the future are examined in the light of the progress which has been made in the past. It is interesting to see that the slope of the curve which we have deduced is not widely different from the curves which history gives us for conventional steam and oil-powered stations.

Using these figures for capital cost and figures similarly deduced for the operating cost of nuclear power stations, we can predict the cost at which these stations will be able to generate electricity, and compare these costs for nuclear power with the cost at which we can expect that power will be generated in conventional power plants.

The design of these conventional power plants is constantly improving, and these improvements give lower capital costs of construction and higher efficiencies. It happens, however, that while these improvements in the design of

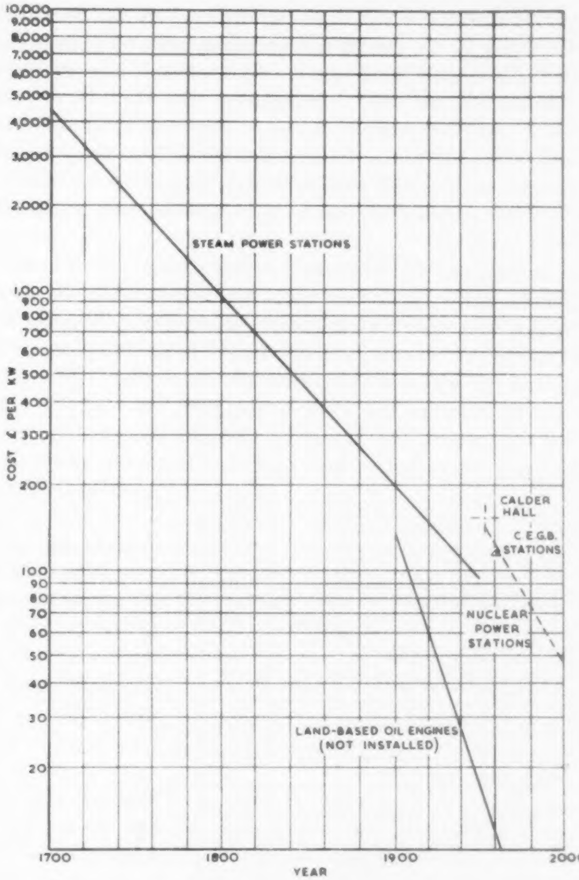

FIGURE 8. *Comparison of 1954 equivalent capital cost of steam power stations, land-based oil engines and nuclear power stations*

conventional stations have been taking place, the cost of coal has been rising in terms of real money values. It has been argued that this cost rise has taken place during a period in which miners have struggled from a position near the bottom of the industrial wage table to a position near its top, and that now that they have reached this position further rises in the cost of coal in terms of real money will be less marked. The trend, however, is well established, and when one remembers the fact that coal resources are becoming more restricted and that underground work is still failing to attract a sufficient number of men, I think that it is reasonable to assume that the upward trend in coal costs is likely to continue.

If we make this assumption and at the same time allow for the improvements which we can expect in the capital and operating costs of conventional power stations, we are able to predict the cost at which we can expect to obtain power from these stations and so make a comparison with the cost of power from nuclear stations. This comparison is shown on Figure 9. From this we see that, if development of nuclear power stations can be continued at its present pace and if the present trend in coal costs continues, nuclear power will be cheaper than power from conventional stations by 1962, and that by 1982 it will amount to less than half the cost.

If this can be achieved, not only shall we have made a great contribution to industry generally, but we shall induce a change in practice in domestic heating and shall find that heat from nuclear energy will be used in the home. This use will naturally not be a direct one; nuclear fuels will be used to generate electricity, and it is this electricity which will be used by the housewife.

It should not be imagined that such development will lead to a reduction in the overall demand for coal. This demand is rising far more rapidly than supplies are expanding, and the report of the O.E.E.C. Committee which studied this problem showed that there would be a large and growing gap which could only be met by the growing use of oil and nuclear power. If in the long run there was a drop in the demand for coal as a fuel, this might be fortunate, for it is an important raw material in the chemical industry and it may be that we are wrong to use it simply as a fuel.

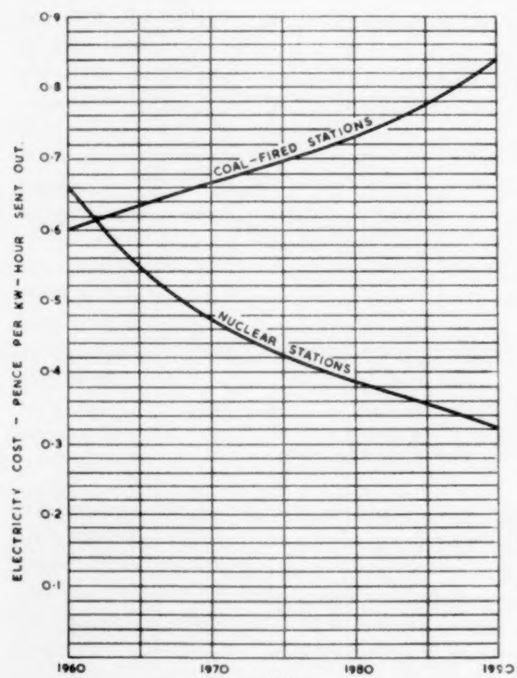

FIGURE 9. *Future cost of electricity from coal-fired and nuclear power stations*

To achieve the rate of progress in nuclear power plant performance that we have predicted will involve a tremendous struggle. The rate of technological development in the nuclear power field is at present very rapid, and it has been maintaining this rate of development since 1946 in spite of the immense care and conservatism which have been

exercised in order to secure freedom from hazard and accident. It is interesting to speculate as to whether this speed can be maintained indefinitely. As the magnitude of the rate of investment in nuclear power plants increases and as the cost of nuclear power drops marginally below the level of the cost of conventional power, there is bound to be a growing tendency towards conservatism. Engineers will look with awe at the magnitude of the financial risk that they may have to take in securing technological advance, and will ask themselves whether such risks are justified. This tendency to retard development can only be avoided if research and development work on a sufficiently large scale is put in hand early enough to provide the engineers with information sufficiently extensive and well founded to justify them in the risks which they will have to take to secure the continuation of the present rate of progress. Vision in designing the programmes of research and development must be even longer in the future than in the past.

DISCUSSION

THE CHAIRMAN: If we attempt to analyse the story that Sir Christopher Hinton has told us it opens up a rather wonderful prospect for our lives for far ahead and not only for our immediate future. If progress continues according to Sir Christopher's description, then some time between 1962 and 1965 the various methods of generating electricity will be about equal in cost; but by about 1982 we should get it at about half the price which electric energy costs to-day. Realize what effect that will have upon the standards of living from that time forward!

MR. C. G. HANCOCK: Sir Christopher Hinton spoke about fission of atoms. Could he say when the fusion of hydrogen atoms will take the place of fission, or whether it will be used in addition? My second question refers to motor cars. It has been reported in the Press, I believe, that motor cars will shortly be run on atomic energy. Could he say whether in his view that is possible and when it is likely to happen?

THE LECTURER: Scientists have recently been predicting development of the fusion process in a much shorter time than they were prepared to predict about two years ago. I am not a scientist. I am an engineer. I said two years ago that it would be about forty years before one saw the fusion process applied industrially; I am still sticking to that figure.

I saw a statement that a nuclear-propelled motor car was about to be put on the market, and wondered what foundation it had. I see no possibility of immediate success in such an application. Nuclear power is economical to-day in favourable conditions where you can use units which are of very large size; it is not an industrially paying proposition in any small unit. Probably the smallest nuclear power plant which is being used effectively is the one in the *Nautilus*, the United States submarine. I would guess the cost of power from this unit to be something of the order of two shillings a horse power. This pays in a submarine; the performance of the American submarine is phenomenal, and the technological development in the building of that submarine is quite a triumph; but it must be regarded as an abnormal and non-industrial application. Industrial nuclear power cannot pay to-day except in the big units; it will not pay in very small units like the motor car.

MR. P. K. SHAHANI: The lecturer made a passing reference to measurement of industrial productivity in connection with the coming of nuclear power, which is not possible at the moment. Could he elaborate on that point?

THE LECTURER: I am not quite certain what you are referring to. I did give figures for a downward trend in electricity costs, and I spoke of the growing domestic uses of electricity which would accompany this falling cost of electricity from nuclear stations as compared with the trend of conventional fuels; but I cannot call to mind any remark about figures for industrial productivity. Can you be more specific?

MR. SHAHANI: Sir Christopher referred to the fact that whereas it was possible to-day to measure productivity of land, it was not possible to measure the productivity of industry, and that this would be better possible with the advent of nuclear power. That is how I understood him.

THE LECTURER: I am sorry, but I do not think I did say this, and I can only apologize if you misunderstood what I did say.

MR. G. VIVIAN DAVIES: With reference to those calculations Sir Christopher made of the cost of nuclear power in the future: I should like to ask him on what basis he allowed for depreciating the capital cost of the stations, bearing in mind the high capital cost and the initial cost of the uranium fuel? As I understand it there is no free market in uranium at the moment; it commands a rather artificial price. How does he visualize the position when such restriction is removed? How does it affect the value? Then again, what value does he place on waste products? I understand that they have a certain value at the moment for military purposes, but this may disappear. My next question is to do with development. Does Sir Christopher believe that there will be enough senior technicians available to put this programme through? I understand that one criticism made by the recent committee on Windscale was of the lack of senior engineers.

THE LECTURER: First of all you asked about the 'write off' of the nuclear power plants. It is at present considered that it is reasonable to write them off in twenty years. The fuel elements are being treated exactly as fuel for a conventional power station, that is, as part of the running cost and not part of capital cost.

Now about the value of the by-products. The estimate that has been made of the cost of electrical power from the industrial stations has not taken any account of the military value of plutonium. The plutonium credit which is given assumes that the plutonium will be used as a fuel in what (in the initial White Paper) were called the second stage reactors. At that time the plutonium credit was assessed as lying between two limits. Its value could not be less than the value of an atom of uranium 235 bought in ore. On the other hand, it could not be more than the value of an atom of 235 in highly enriched uranium from a diffusion plant. In between those two extremes what was thought to be a reasonable value was fixed. But in research work carried out during the subsequent eighteen months it was found that plutonium could not satisfactorily be used as a fuel in thermal reactors, because of the formation of the higher plutonium isotopes 241, 242, which are not fissionable and which are wasteful absorbers of neutrons. Therefore the plutonium can only be completely used in a fast reactor. The problems of developing the fast reactor became no less during that period; it is an extremely difficult project. For these reasons the plutonium credit was reduced. Fortunately the capital cost which was quoted by the firms for the first reactors came out rather lower than was expected, and this rectified the position to some extent. You notice that I quoted the cost from those reactors as 0.66 pence per unit, whereas if you look at the first White Paper you will find it is quoted as 0.6 pence per unit: it is the difference in plutonium credit which accounts for that change. You can really only fix plutonium credit when you know how you are going to work a fast reactor and what it is going to cost. Then obviously the plutonium credit should be the sum of money which will enable you to produce electricity at the same price in your primary thermal reactors and in your secondary fast reactors.

Your last question concerned technicians. There is, of course, a national shortage of scientists and engineers and it must be a matter for argument as to what constitutes any industry's fair share of the number available. There is a specific problem though, in that with this overall shortage of scientists and technologists it is, in these days, particularly difficult to get people to do production work. Research is interesting; engineering design (if it is original) is interesting; but many men (particularly young men) feel that production work is routine. This feeling is encouraged by the increase of automation on process plants.

I think production work is still interesting because it involves human contacts, it involves an overall appreciation of all problems; engineering, research, cost, and human. Unfortunately many young men will not accept this. I believe that one of our most important problems is to make certain that enough young men are interested in production management and that they realize that though (with the growth of automatic control) the controls may be looking after the plant 99 per cent of the time, they must nevertheless be on the alert so that they can deal with the abnormal circumstance which is outside the scope of the control. This is a pressing and, I think, not an easy problem of modern management. Now will you kindly repeat your other question?

MR. VIVIAN DAVIES: I asked about the value being placed on the actual uranium fuel. I understand it is an artificial value at the moment.

THE LECTURER: The cost of uranium fuel elements arises to a large extent from the cost of uranium ores, and to a rather smaller extent from the cost of ore extraction, purification and the metallurgical processes. I, personally, doubt whether the cost of uranium ore will rise materially. It is true that the market is to some extent artificial in that in the free world uranium is mainly bought by the American and British governments and that they have sponsored much of the mining development. I do not think that this has resulted in prices far away from the price which is related to the demand. I doubt whether the demand will increase greatly, because it seems unthinkable that the military demand will continue indefinitely. I therefore consider that the price is not highly artificial, and I do not believe it will prove to be very unstable.

MR. J. F. PERRIN: I should like to ask Sir Christopher what will be the procedure for working a nuclear power station on peak loads? I understand one can shut a station down quickly, but I believe it would take a very long time to start up a nuclear station. Do you have to dump the excess energy in some way?

THE LECTURER: You are wrong in believing that it is difficult to get the stations of the type now being built on to load quickly; but a problem may arise as the technological development proceeds, arising from what is called xenon poisoning. Briefly, xenon is a poison, built up in a reactor, which is normally destroyed by neutron irradiation, but which, when the reactor is shut down, goes on building up and stops you from re-starting a reactor until a certain period of time has passed. In the low rated reactors which are being built to-day this is no problem, but as the rating increases it becomes more serious. It is one of the technological difficulties which has got to be overcome, but it is not an immediate problem.

MR. L. N. FRASER (Deputy County Planning Adviser, Essex): Sir Christopher said that the power stations now being built will be written off in twenty years. I assume he means that to be understood in terms of working out the cost per kilowatt from a nuclear power station. I say I am assuming that, because in a recent public inquiry on the proposed power station at Trawsfynnyd, a statement was made to the effect that the reactor would only be there for twenty years—and then what happened? This was a new situation, which was not brought out in the public inquiries on other nuclear power stations (e.g. Bradwell). Is it in fact true that the life of the power

station as a power station (not financially, as to writing off the capital cost) is about twenty years? If that is so, then with all the other capital invested there in the ordinary boilers and the turbos and the whole of the ordinary electrical and engineering installations, will it be possible either to replace the original reactor with another reactor and go on using the same generating equipment, or to replace it by an oil-fired installation? I mention this latter possibility because the site at Bradwell on the Essex coast has deep water and a new, specially built jetty providing access for tankers (if ever required in the future).

Secondly, if in fact these three nuclear power stations now being built cease operating in twenty years, that means you are going to lose that amount of generating capacity to take the basic load in about 1980. Therefore, about five years previously you are going to have to start building three more to take up that slack, and so on *ad lib*. As the first power stations to be built come to a standstill others must be ready to take up the resulting slack, and that seems to me a most complicated programme to arrange. I wonder if Sir Christopher could give some indication as to how he is approaching that problem?

THE LECTURER: Let me point out straight away that you are assuming a difference between nuclear stations and conventional stations which does not necessarily exist. Conventional stations are written off, from the accountancy point of view, in about twenty years, and I was talking about the accountancy write off. Whether the life of a nuclear station will be longer I could not say at the moment. The estimate of a twenty-year life is a reasonably conservative one. Although conventional stations are written off in twenty years, a number of them are still working after thirty-five years. It is interesting that whereas people complain because in the case of a nuclear station the write-off period is given as twenty years, they complain when a conventional station is still working after, say, thirty years, that it is obsolete and looks an eyesore. At the end of the useful life of the nuclear reactors (be it twenty years or twenty-five years) in all probability the turbo-alternators and heat-exchangers will still be in reasonable condition. It would then be possible to replace the reactor and install a new one to work with the same turbo-alternating machinery. But in fact it is highly improbable that this would be a reasonable course; technology will by that time have advanced so far that one would wish to use higher pressures and higher temperatures; to do this, new turbo-alternators will be required. What I therefore anticipate is that at the end of the useful life of the nuclear power plants now being built, they will be demolished. The only part of the station which, in all probability, cannot be demolished is the biological shield around the reactor itself; this is comparatively small in relation to the scale of the rest of the station. Having done this demolition, one will build a new station on that site, in such a way as to mask the comparatively small block of the biological shield which will probably have to remain for a large number of years.

THE CHAIRMAN: I am sure everyone in this room will wish me to thank Sir Christopher Hinton for a magnificent Trueman Wood Lecture. I have heard a number of lectures in that series, and his decidedly is one of the best. His words have stimulated us to think carefully upon a subject of the greatest importance, and by doing so he has increased the desire we all have to learn more, and also to give that co-operation which is going to be essential if the government is to provide the money, collected from the tax-payers—I say that advisedly—for these new and advancing developments. Lectures like Sir Christopher's will go a long way to inducing the general public to be willing to see the government provide the money necessary to develop these undoubted future benefits.

A vote of thanks to the Lecturer was carried with acclamation, and the meeting then ended.

CLOTH FROM THE CHEMIST

A Dr. Mann Juvenile Lecture

by

J. R. WHINFIELD, C.B.E., M.A., F.R.I.C., F.T.I.,

of Imperial Chemical Industries Limited

Monday, 6th January, 1958

I think we might begin by just talking about cloth in an everyday sort of way and leave the chemist rather out of the picture for the moment.

Here is a piece of very ordinary cotton calico which could be used for many purposes. If you were to pull out the threads and then untwist them you would arrive at the individual cotton fibres. You would find that these are mostly about $1\frac{1}{2}$ inches in length and that across their width they measure no more than about half-a-thousandth of an inch. There are at least 10 million of these fibres in this piece of cloth, which itself weighs barely 5 oz., and they are composed of a substance called cellulose. This is the great building material of the vegetable kingdom, where it is very widely distributed. I shall have a lot more to say about it later on.

Although the cloth is entirely made up of these minute and slender fibres, it is nevertheless quite strong and cannot easily be torn. But here is another piece of the same cloth that has been treated with dilute acid, and although its appearance is unchanged, it has now lost most of its strength and tears very easily indeed. Everyone knows that if cloth is to be of any use it must be reasonably strong, but already you see that strength, for all its importance, is not just something to be taken for granted. There are reasons why cotton is strong and why it can be made weak, but it is only within the last thirty years that the chemists have found out what these reasons are, and this discovery was naturally to prove of great help when they came to make fibres for themselves.

Now for another very obvious quality of the cotton cloth: if I crumple it up in my hand and then throw it down on the table, it remains crumpled. However, not all cloths behave in this way. When I crumple up this piece of cloth made from wool, the creases disappear as soon as I let it go. Wool fibres are larger than cotton fibres—longer and thicker—but this behaviour of the wool cloth has nothing to do with any question of size. It is due to the fact that these fibres consist, not of cellulose, but of a protein called keratin. The fibres which the chemist has been making in recent years consist neither of cellulose nor of keratin, but of substances which are not found in nature at all; but some of them turn out to be as springy as wool.

I now come to another property altogether. If I put a light to the cotton cloth it immediately catches fire and is quickly consumed. Here again, wool shows to advantage, and so do man-made fibres such as nylon and 'Terylene' (Figure 1).

FIGURE 1. *Inflammability: the cotton cloth* (left) *has taken fire, but the wool cloth* (centre) *and the Terylene cloth* (right) *have not*

But the very first man-made fibres were derived from nitrated cellulose, which is so inflammable that it burns with almost explosive violence. This nitrated cellulose will dissolve in various organic solvents to give treacly solutions; and by forcing such solutions through very small holes and allowing the solvent to evaporate, the nitro-cellulose is readily obtained in the form of long filaments (Figure 2). This method of making fibres is called dry-spinning.

This idea was put into practice by a French nobleman named Chardonnet towards the end of the last century. His 'nitro-silk', as it was called, was the first commercially produced man-made fibre, but it enjoyed only a limited success and was soon superseded by others.

Way back in the middle of the nineteenth century, John Mercer discovered that cotton behaved in a peculiar way when treated with strong solutions of caustic soda—I am sure you have all heard of mercerized cotton. Many years later, another English chemist, C. F. Cross, found that if carbon disulphide was added to the mixture of cotton (or other forms of cellulose) and caustic soda, the cellulose dissolved, so that he obtained a highly viscous and strongly alkaline solution. Cross called this Viscose. Again, this solution can be forced through fine holes and coagulated as filaments, but here the coagulation has to be brought about in a liquid bath. This process is called wet-spinning, and this is the way in which the well-known viscose rayon is made. There is another form of rayon called acetate rayon, which is made from cellulose acetate by dry-spinning. This was introduced many years after viscose rayon (about 1925) and from that date until less than 20 years ago, these two fibres reigned almost supreme among the achievements of the chemist in this realm. They are still very important indeed, and you will notice that they both start from cellulose. I must now tell you something more about this substance. Cellulose is a carbohydrate. Its molecule is built up from atoms of carbon, hydrogen and oxygen.

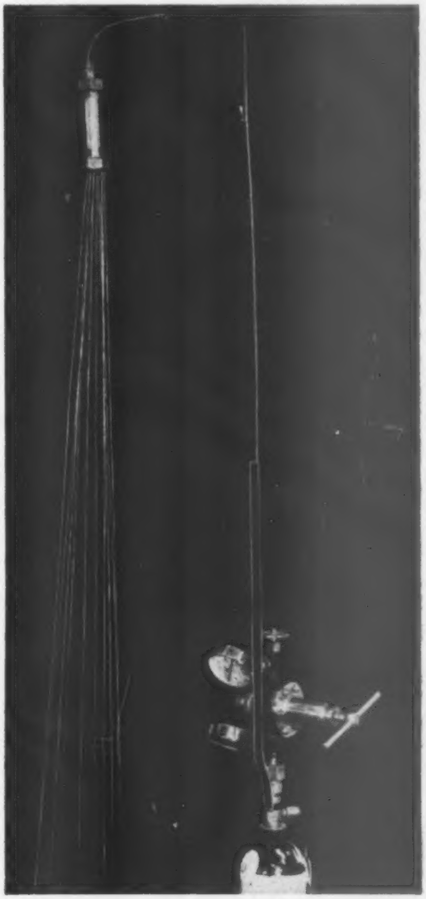

FIGURE 2. *Dry-spinning of nitro-cellulose, the first man-made fibres*

Cellulose is also a high polymer and the cellulose molecule as a whole can be likened to a long string of beads, each bead representing a repeating group of the above three atoms ($C_6H_{10}O_5$).

You need not bother too much about the actual number of these beads or groups in the cellulose molecule. But think of something between 500 and 1,500 and you won't be far wide of the mark. With molecules of this immense size a few groups, more or less, makes little difference.

But if you think of several of these molecular chains lying, not higgledy-piggledy, but stretched out roughly side by side, you will at once begin to have some conception of the molecular structure of a fibre in which the long molecules lie lengthwise along the fibre axis.

This conception of long molecules, which applies to many materials other than cellulose (to keratin, for example), is now well established, but only within the past thirty years. Men like Mercer and Chardonnet and Cross knew nothing about it whatever.

They did, however, know something else about cellulose: that it could be very easily broken down into the familiar sugar called glucose. Glucose is a crystalline substance, entirely different in character from cellulose. Its molecule is quite small and consists of 6 atoms of carbon, 12 atoms of hydrogen and 6 atoms of oxygen ($C_6H_{12}O_6$). How then do we get from cellulose to glucose?

Let us go back to our chain of beads symbolical of the cellulose molecule. Each of these beads consists of 6 atoms of carbon, 10 atoms of hydrogen and 5 atoms of oxygen. To each point where the beads are joined together we bring up a molecule of water. The junctions snap, the water adds itself to the beads and each becomes a molecule of glucose: it's as simple as that.

Suppose we had a chain consisting of a thousand beads, and therefore having 999 links. We then need 999 water molecules to separate all the beads in order to change the cellulose molecule completely into one thousand glucose molecules. But we need not go all the way. We could imagine that we have only two molecules of water, and that these attack two links at random. Our long chain has now broken down into three parts whose average length is just over 333 units. This is really a catastropic change brought about by these two little water molecules. What does it mean in practice? It means this: if you start chopping up the long molecules in a fibre, the fibre is going to lose strength very rapidly and before you have got very far it will lose all its strength.

If the fibres in a yarn are weakened, then the yarn will be weakened; and if the yarn is weakened then the cloth itself will also be weakened.

And so we come back to that piece of tendered cloth which I showed you earlier. The reason why we can tear it so easily is because in treating it with acid we have already begun this chopping up of the long cellulose molecules of the constituent fibres. If we had persevered with the treatment we could have broken every single link in every chain, and we should then have been left with nothing but glucose or barley sugar. But it is a one-way street: you cannot start with a stick of barley sugar and end up with a piece of cloth.

Now, as I have already said, there are many other tough and strong materials found in Nature besides cellulose, whose molecules consist of long chains built up from substances other than glucose.

But here are two more such substances in the form of massive sheets, tough and strong beyond doubt, but which are not found in nature and where the job of building up long molecules from small ones was done first in the laboratory

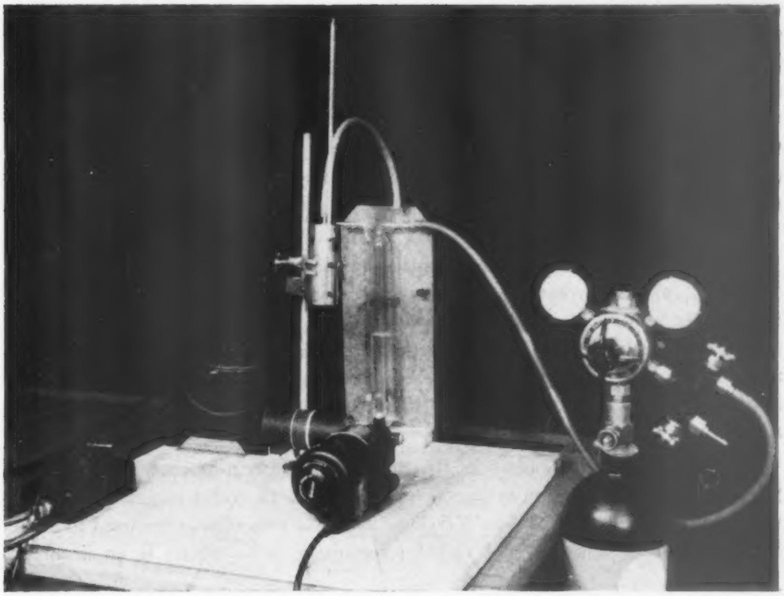

FIGURE 3. *Melt-spinning of Terylene*

and now in the factory. One of these is the material from which nylon fibres are made, and the other is one from which 'Terylene' fibres are made.

These substances are converted into fibres not by being first dissolved, but merely by being melted. The melts themselves are sticky liquids which can be forced through fine holes in the usual way, and the emergent streams solidify on cooling. We have here a small apparatus with which we shall be able to spin a little hank of 'Terylene' in this way (Figure 3). However, the job of making the fibre is not completed with the spinning of the hank. If we take this hank and pull it, you will see that it stretches in a remarkable way, extending to about four times its original length. It then stays put and does not shrink back when we stop pulling. This process is called drawing, and it applies both to 'Terylene' and nylon. In performing it we are pulling out the long molecules of the material until they mostly lie side by side, forming, in places, a three-dimensional pattern which we call a crystallite. This confers both strength and stability on the fibres.

The man who really started all this was a very distinguished American chemist named W. H. Carothers. He began his work in the late 1920s and unfortunately did not live to see its tremendous outcome.

He began by finding a very simple and straightforward method of joining

certain kinds of small molecules together to form chains, and this led him eventually to the discovery of nylon. In a sense it was the old business of stringing beads together, but now the beads did not represent glucose but organic acids such as adipic acid, and amines like hexamethylenediamine. I might say that nylon was by no means the first fibre to be discovered by Carothers, but the earlier ones could not be turned to practical account. Some of them were unstable (like the fibre invented by Mr. Alec Guinness in his film *The Man in the White Suit*), and others melted at low temperatures and would not stand up to the rigours of the wash tub. But in nylon Carothers had a winner.

I don't think a Christmas lecture is the occasion for going into a lot of detailed chemistry, which is what I should have to do in order to explain the nature of nylon more fully. Will you accept it from me that of all the molecules or pairs of molecules which can be linked together to form long chains, very few give materials from which fibres can be obtained? And by the time Carothers had finished his work it rather looked as if he had explored all the possibilities and that there was nothing more to be done.

Well, research often looks like this for a time, but in 1941 I had the good fortune to find just one more pair of molecules which could be linked together to give a useful fibre. This was 'Terylene', and the two substances used to make it were a rather obscure acid called terephthalic acid, which is an aromatic

FIGURE 4. *The Lecturer and two members of his audience making fibres with a garden syringe*

substance related to benzene, and a liquid called ethylene glycol, which was already produced, mainly for use as an anti-freeze in motor cars.

The actual making of the polymer from these two substances is a fairly simple matter. They are just heated together. Water is split off in the reaction and is led away. The residue, which is at first a mobile liquid, gradually increases in viscosity until finally fibres can be drawn from the melt or spun by forcing it through fine holes in the way I have just shown you.

I referred earlier to the quality of strength in textiles and later explained how this is dependent on the long chain molecular architecture of the fibre and why, if we begin to fracture these chains, the strength of the fibre rapidly declines. The new synthetic fibres like nylon and 'Terylene', are exceptionally strong and their chains are much less readily fractured than those of cellulose or wool, so that many treatments which would virtually destroy cotton or rayon or wool have little effect upon them.

'Terylene' materials, in particular, are extremely resistant to crumpling, but if a crease is once ironed into them at a high temperature it cannot subsequently be removed. That is why you see so many permanently pleated skirts, for example, made from 'Terylene' often blended with wool or with other fibres.

Fibres like cotton, wool or silk absorb appreciable quantities of moisture from the air, but these modern synthetic fibres absorb very little. One consequence of this is that they easily acquire a charge of static electricity. Here we have a rather complicated piece of electrical equipment surmounted by a metal plate and a lamp which is just glowing. If we rub a piece of nylon or 'Terylene 'cloth and then hold it near the plate you will see that the lamp suddenly flares up. This is due to the static electricity generated on the fabric, but fortunately we can treat these materials with various agents so that they no longer display this rather troublesome property.

GENERAL NOTES

THE ROYAL ACADEMY AT THE CROSS ROADS

This year's Royal Academy Summer Exhibition is a disturbing show. We are so used to a certain somnolence, that the greater influx of 'contemporary' work makes us restless. In recent years the rebels have been segregated in distant rooms, inspected only by the more determined pedestrians. This year, visitors are confronted with at least one perplexing creation on every wall. If the Selection Committee repeats the dose for a few more years, visitors will feel a sense of æsthetic re-invigoration. Nevertheless, the President, Sir Charles Wheeler, deserves credit for giving his flock the lead.

John Bratby's three large works readily impose themselves. He has a singular colour sense, and a most disruptive style, his crowded figures being positively volcanic. The flesh of the actors in his *Film Studies* seems to be showing through their skin. In another work, he manages to incorporate five portraits of himself. Ruskin Spear, a more mature painter, is once again the outstanding artist in the show. His studies are

mostly of ordinary people: *Tom Chalk*, a seventy-three-year-old draper's porter, a smug *Young Contemporary*, and one unusual model whose ancestral characteristics are most pronounced. He is *Fred*, a superb member of the ape family, ironically hung in one of the corners of the great Gallery III, which has so often been reserved for monarchs and society beauties. It is a healthy sign, that the Academy has taken to laughing at itself.

Just how John R. Merton's *Countess of Dalkeith* came to be accepted with such enthusiasm, will remain one of the major mysteries in the history of the Institution. Few would assert that this pretty illustration has great appeal as a work of art, though it is impossible to deny that the painter has quite uncanny skill. Among the other portraits, the eastern rulers have little vitality. Simon Elwes, however, has produced a sympathetic and pictorial interpretation of *The Rt. Rev. C. S. Woodward, D.D., M.C.*, whose white and crimson apparel exhales poetry. Carel Weight's second, annual, *Orovida Pissarro* is even better than the first, while Augustus John gives us a quick, intellectual figure in *Theodore Powys*. Stanley Spencer is as unaccountable as ever; his abundantly muscled *Mrs. Marjorie Metz* is the epitome of amplitude.

Less familiar artists, and by no means always the 'contemporaries', keep breaking through. *Wedding*, by Shirley Pond is a flower-decked procession of coloured people leaving a church, the entire scene being in subdued purples and blues that give a smouldering effect. A few painters have provided a snatch of elusiveness. *Still Life with Sheep's Skull* (the skull very difficult to find) and *Snowstorm*, both by Mary Smith, catch the eye. The ten-foot *Model Maker* by Norman C. Blamey is a streamlined interpreter of science. James Fitton almost sets the end wall of Gallery II alight with *The Painter's Wife* surrounded by coloured prints. John Ward and Gerard de Rose both command attention with a certain austerity, and Paul Wyeth's groups with their frank flamboyance.

The sculpture consists of capable carving and modelling. There is little that is outstanding. David McFall's powerful head of Sir Winston Churchill, Eric Schilsky's sensitive bust of Arnold Mason, and Sydney Harpley's romantic, but lovely, interpretation of his wife, are notable among humans. There are, however, a few vital birds and dogs. Water colours are largely derivative, though the flowers of Robert Austin are delightful. There are about ninety Architectural Drawings, nearly all in styles far more advanced than anything in the sister arts of painting and sculpture; though they are already beginning to grow commonplace. The rigid economies of the past twenty years are having their effect.

G. S. SANDILANDS

DESIGNS OF THE YEAR

At the Design Centre on 8th May, H.R.H. The Duke of Edinburgh presented certificates to the manufacturers of the products chosen as the outstanding 'Designs of the Year'. All products shown at the Design Centre during the previous twelve months were eligible for these awards, which were instituted in 1957 (see *Journal*, 24th May, page 555). The number has this year been increased from twelve to twenty, in order to widen the range of industries and prices covered, and the awards have been made on the recommendation of four independent members of the Council of Industrial Design's Design Index Selection Committee: Sir Walter Worboys, B.Sc., D.Phil., Hon.A.R.I.B.A. (*Chairman*), Mr. Noel Carrington, Mr. Geoffrey Dunn, Professor Wyndham Goodden, O.B.E., Hon. Des.R.C.A., and Mr. Jack Howe, F.R.I.B.A., F.S.I.A. The goods they have singled out include textiles, carpets, furniture, sanitary and light-fittings, cooking utensils, table-ware and wall-paper.

'Designs of the Year' are on view at the Design Centre until 12th June.

AWARD OF THE SOCIETY'S BRONZE MEDAL

At Work, *by Willaddaragamage Jinaseena, from The Royal Drawing Society's Exhibition. As announced in the last issue of the Journal (p. 456), this picture has been awarded the Royal Society of Arts Bronze Medal*

OBITUARY

We record with regret the death of three Fellows of the Society:

SIR NORRIS KENYON

Sir Norris Kenyon, leader of the Conservative Party on the London County Council, died on 28th April at the age of 54.

Kenyon's adult life was largely devoted to local government and public service, and in particular to the affairs of Paddington. He was elected to that Borough Council in 1927, became an Alderman of the Borough in 1938, and its Mayor in 1950–2. Meanwhile, as the representative of South Paddington, he had entered the wider sphere of the London County Council, and his character and abilities were such that even before Mr. Henry Brooke relinquished the Leadership of the Conservative Party on the L.C.C. in 1952, Kenyon had been regarded as his undoubted successor.

As a magistrate, Kenyon's deep interest in the welfare of young people found expression in whole-hearted service outside politics. He was Chairman of the Metropolitan Juvenile Court from 1946, of the Paddington Boy Scouts' Association

and of the North Paddington Boys' Club. He was also a Governor of St. Marylebone Grammar School and the Royal Masonic School for Boys.

Sir Norris Kenyon was elected a Fellow of the Society in 1952.

SIR IAN ORR-EWING

Sir Ian Orr-Ewing, Conservative Member of Parliament for Weston-super-Mare since 1934, died at Bristol on 27th April, aged 64.

The son and grandson of former Members of Parliament, Orr-Ewing was born on 4th June, 1893, and educated at Harrow and Worcester College, Oxford. During the 1914–18 war he served with the Royal Scots Fusiliers, and was wounded in action. He first stood for Parliament at Gateshead in 1929, but was defeated in a four-cornered contest. In 1931, when prospective Member for the St. Ives division of Cornwall, he withdrew in favour of Mr. Walter (later Lord) Runciman. In 1934 however, he was elected Member for Weston-super-Mare in the Conservative interest by a comfortable majority, which he increased at the General Election in the following year. It speaks for Orr-Ewing's popularity and capability that he was able to retain this seat in the 1945 General Election, which saw the loss of so many Conservative seats to the Labour Party.

Orr-Ewing was Parliamentary Private Secretary to five Ministers: the Financial Secretary to the Treasury (1935–6), the Minister of Agriculture (1936–9), the Chancellor of the Duchy of Lancaster (1939), the Minister of Food (1939–40) and the Postmaster-General (1940). He served as a Member of the Royal Commission on Rhodesia-Nyasaland in 1938. He was knighted in 1953.

Sir Ian was elected a Fellow of the Society in 1948.

LT.-COL. G. R. S. WILSON

Lieutenant-Colonel G. R. S. Wilson, C.B.E., R.E., Chief Inspecting Officer of Railways, Ministry of Transport and Civil Aviation, since 1949, died on 20th March, aged 61. At the time of his death he was completing his report on the Lewisham railway collision.

Wilson's career with the Railway Inspectorate began in 1935, when he was appointed Assistant Railway Inspecting Officer; and after a brief interruption for service as Assistant Director of Railways with the B.E.F. in France during the early part of the Second World War, he rejoined the Inspectorate in June, 1940, becoming an Inspecting Officer in the following year, and Chief Inspecting Officer in 1949. He was a member of the permanent commission of the International Railway Congress Association.

The most important result of Wilson's work for British Railways was the adoption of a new automatic train control equipment in 1956, after a prolonged and most thorough series of tests carried out under his supervision. To the detailed study of conditions and effects which this operation involved, he devoted all his knowledge, experience and delight in technical problems. But perhaps his full stature was shown in the inquiries which he conducted into the railway accidents at Harrow in 1952, Barnes in 1955, and Lewisham in 1957. In tragic circumstances and under concentrated public notice, his investigations were both searching and gentle; though determinedly bent, in each case, upon establishing cause and responsibility, he reconciled an absolute regard for truth with an uneffusive sympathy that told of genuine personal distress. This care for human feelings was indeed as much a characteristic of Wilson as his professional ability, and won him general respect, trust and affection.

Lt.-Col. Wilson was appointed C.B.E. in 1953. In March, 1954, he delivered a Cantor lecture, 'Safety on the Railways', to this Society, and he was elected a Fellow in the following year.

CORRESPONDENCE

TRISECTION OF AN ANGLE

From *Dr. L. A. Beaufoy, M.Sc.(Eng.), M.I.Mech.E., M.Am.Soc.C.E., The Athenæum, Pall Mall, London, S.W.1*

The fallacy which Mr. Critchfield thinks must be present in his proposed geometrical construction for the trisection of an angle (see *Journal* for May, 1958, page 459) is—alas!—there. It resides in his basic assumption; this is stated in the last three lines of his 'Method', and is that if a chord of a circle is divided into three equal parts, these subtend equal angles at the centre of the circle. This is not so and if, for his illustration, Mr. Critchfield had chosen a large angle (of nearly two right angles) he would have seen clearly that it was not so. To trisect an angle it is necessary to trisect the *arc* of the circle, not the chord; therein lies the difficulty of the problem. Geometrical constructions are of course possible for the special cases of one right angle and two right angles, but I have not so far seen one for the general case of an angle of any size.

NOTES ON BOOKS

SOVIET SPUTNIKS. *Soviet News Booklet No. 25. London, 1958. 1s 3d*

The introduction to this booklet states that it is based on material published by Soviet scientists in connection with the launchings of the Sputniks. An impressive list of Russian Academicians and Professors is then given and many of the names are recognizable as those much quoted in the daily press. It appears, in fact, that the booklet is very largely a series of statements and articles by these authorities strung together in a more or less logical sequence.

The first section philosophizes on the achievement of earth-bound man and points the way that Russia has led the world in the science of space rocketry. It is true that Tsiolkovsky was a pioneer in the theory of rocket flight, and no one can deny that the U.S.S.R. launched the first earth satellites, but these achievements are somewhat spoiled by the efforts to impress the reader that all 'firsts' were Russian. A much more impressive picture would have been to show how in spite of earlier German and American advances, Russia had achieved her success over a relatively limited period of time.

The major portion of the booklet deals first with the problems of launching a satellite and secondly with its objectives. The discussion on launching is divided into a number of aspects—engine operation, rocket structure, flight path and speed, orbits and their life. None of these receives a very satisfactory treatment from either a technical or a lay point of view. In most cases this is because the statements are of an elementary nature, but are introduced by technical terms or inadequate explanations. Possibly much of this is due to poor editing. One is certainly left with the impression that this section is made up of a number of press cuttings pasted together in a somewhat disjointed manner. One small but interesting point in this part is an explanation of why satellites burn up on re-entering the atmosphere. No claim is made that the Sputnik I fell to earth either in America or anywhere else.

The second section is, on the whole, much more satisfactory. It gives some details of the upper atmosphere, the studies which satellites permit of its constitution, movement and other features, the observations which can be made of geophysical data such as the earth's magnetic field, its shape and its mass distribution. This is followed by a discussion on the biological aspects of space flight and a fairly long description of the 'first passenger to tour space' and the problems connected with it. Again the statements are mainly a repetition of news items which appeared when the Sputniks were launched, and although it is claimed that a great deal has been learned there is no indication of what this is.

Finally some predictions are made about the future, including flights to the Moon and to Mars. Here again the impression is given that Soviet scientists exclusively

have progressed towards this end. The figures quoted are, in fact, well known to all students of astronautics.

Summarizing, it can be said that there is practically no information on Soviet Sputniks, but a considerable collection of general information on satellites and space. This is distinctly coloured in its presentation and could be quite misleading to a lay reader.

A. D. BAXTER

SHORT NOTES ON OTHER BOOKS

SIXTEEN QUESTIONS ABOUT THE SELECTION AND TRAINING OF MANAGERS. *By L. Urwick. London, Urwick, Orr & Partners*, 1958. 2*s* 6*d*

Whom should a business look for as potential managers, when and how? Having selected them, how should it train them and what facilities exist to help in this? Such are the primary questions considered and answered by Colonel Urwick, founder of a well-known firm of management consultants.

CLOUD STUDY: A PICTORIAL GUIDE. *By F. H. Ludlam and R. S. Scorer. London, John Murray*, 1957. 12*s* 6*d net*

Prepared under the auspices of the Royal Meteorological Society, this authoritative introduction explains simply and clearly how clouds are formed. Most of the information is given by means of captions describing seventy-four excellent photographs, some of them in colour.

A PRIDE OF POTTERS. *By Derek Peel. London, Arthur Barker*, 1957. 10*s* 6*d*

Telling the story of the Adams family, who have been potters in Staffordshire for 300 years, and whose firm continues to produce distinguished work to-day. The illustrations are most interesting, particularly those showing the eighteenth-century Adams blue jasper ware.

FROM THE JOURNAL OF 1858

VOLUME VI. *25th June*, 1858

OCCUPATIONS OF EXAMINATION CANDIDATES

(*1858 was the first year in which the Society's examinations were held at local centres, under the supervision of local boards: and as we saw from the extract printed in the last issue of the* Journal, the *Council laid down precise rules for the working of the papers by the candidates. The following, which is taken from the Secretary's Report to the Seventh Annual Conference between Representatives from the Institutions in Union and the Council of the Society, shows the wide variety of callings followed by the candidates to whom these rules were applied. Their ages ranged from 16 to 49.*)

The numbers of papers looked over by the Examiners was 582, and the Certificates awarded were as follows: Fifty-three of Excellence, or the 1st grade; one hundred and thirty-two of Proficiency, or the 2nd grade; and one hundred and seventy-six of Competency, or the 3rd grade. Two hundred and twenty-two papers failed to obtain a sufficient number of marks to justify the award of any certificate in respect of them. With regard to the occupations of the Candidates, the returns show that there were 46 clerks, 7 mechanics, 6 book-keepers, 7 engineers, 4 shipwrights, 7 warehousemen, 2 schoolmasters, 9 printers and compositors, 4 chemists and druggists, 3 surveyors, 3 porters, 3 butchers, besides a grocer, turner, woolsorter, saddler, clothdresser, veterinary surgeon, plasterer, watchmaker, brushmaker, iron moulder, draper, draper's assistant, letter-carrier, a gentleman's servant, a butler, an auctioneer, a millwright, cabinet maker, house decorator, chain maker, mechanical draughtsman, stover, weaver, shovel maker, bricklayer, cardroom hand, carpenter, bank cashier, tobacconist, spinner, joiner, worker in a chemical laboratory, governess (5 other women), confectioner, marqueterie cutter, engraver, finisher, painter and glazier, assistant master of workhouse, mason, music seller, overlooker.

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Signatures of three fellows, at least one of whom must sign on personal knowledge :

Name in Block Capitals	Signature
[..............................]	.... *(on personal knowledge)*
[..............................]	....
[..............................]	....

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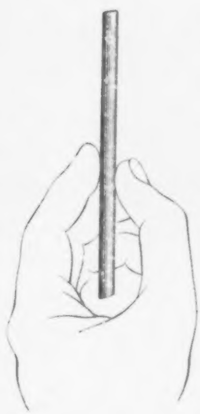

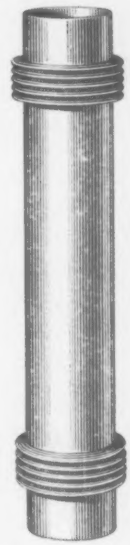

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